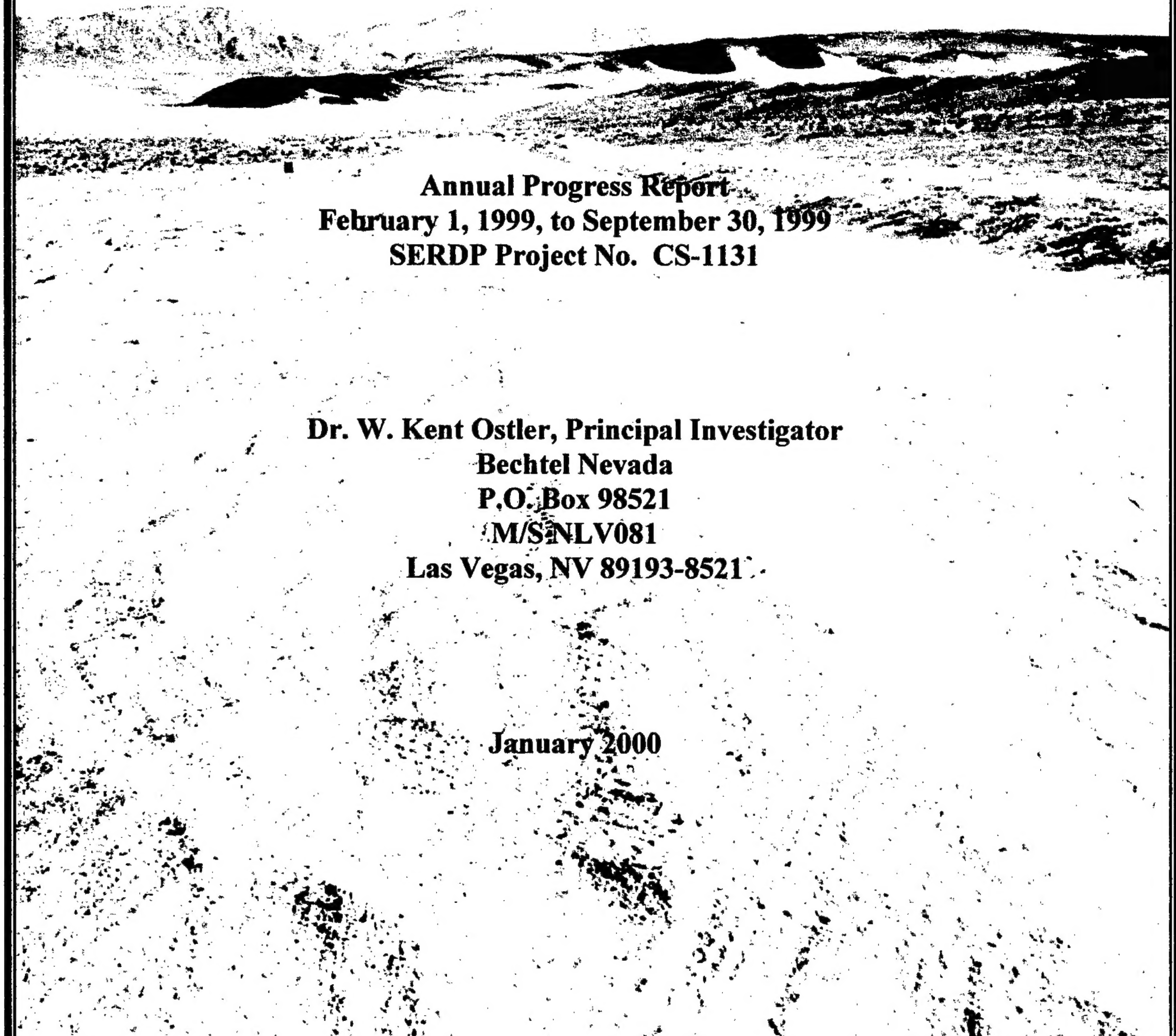
DIAGNOSTIC TOOLS AND RECLAMATION TECHNOLOGIES FOR MITIGATION IMPACTS OF DoD/DOE ACTIVITIES IN ARID AREAS



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An essential component of monitoring to determine the spatial extent and degree of military impact is the ability to accurately assess site changes through time as training areas undergo normal use under varying climatic conditions. Historically, monitoring techniques have been primarily limited to expensive, labor-intensive ground collection of data such as plant canopy cover by line-point or line-intersect methods, and plant density by quadrat sampling techniques. Additionally, accessibility to the range by field biologists has been limited at many sites to only one week each month due to intensive military training exercises, making it difficult to obtain sufficient field data during narrow windows of opportunity.

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1.0 INTRODUCTION

Approximately 70 percent of all U.S. military training lands are located in arid areas. Under current technology, it is estimated that up to 35 percent of revegetation projects in arid areas will fail. Applying the results of this project will increase the success of restoration and possibly save as much as $5 million annually within the U.S. Department of Defense (DoD). Strategies proposed here will improve the efficiency and effectiveness of revegetation efforts, reduce the risk of failures in restoration efforts, and maximize the use of areas for training or other mission-related uses. Diagnostic tools developed by this program will provide a means to bridge the gap between deficiencies common to remote sensing using satellite imagery and the high cost and time associated with detailed ground surveys. They will significantly reduce collection costs and time, while increasing data quality and reliability. Additionally, restoration techniques developed during the project will ensure continuation of military testing and training (currently threatened by deteriorating site conditions), U.S. Department of Energy (DOE) operations, and facilitate acquisition and characterization of new lands needed for increased DoD and DOE activities in the future.

The project is a cooperative effort between DOE, DoD, and selected university scientists with a focus on mitigating military impacts at Fort Irwin. Fort Irwin is the Army's National Training Center located near Barstow, California, in the Mojave Desert. The approach focuses on specific problems of this site, but is suitable for other DoD and DOE facilities in arid and semiarid areas. Diagnostic tools to be developed will also be applicable to wetter areas of the U.S.

Techniques developed as part of this study will provide users of models such as the Army Training and Testing Area Carrying Capacity (ATTACC) and other models used in Land Condition Trend Analysis (LCTA), and the Terrain Modeling and Soil Erosion Simulation (TMSES) programs, with cost effective methods to provide needed information. New rehabilitation and restoration techniques will find immediate application for Integrated Training Area Management (ITAM) personnel located at military facilities in the western U.S. where ecosystem sustainability for training and testing is at risk.

Innovative technologies developed by the study will provide valuable tools to ensure continuation of military testing and training currently threatened by deteriorating site conditions. Techniques developed in this project will decrease the risk of violating particulate standards of the Clean Air Act that could potentially restrict or reduce testing and training exercises.

2.0 GOALS AND OBJECTIVES

This project is designed to overcome current gaps in diagnostic capabilities needed to distinguish between various degrees of sustainable and nonsustainable impacts due to military training and testing or earth-disturbing activities in desert ecosystems. The project will also develop and evaluate new and cost-effective techniques for rehabilitation and restoration of such disturbed

habitats. These diagnostic tools will enable management to maximize utilization of limited training environs and thus increase operational readiness.

Technical objectives of the project are to:

(1) Develop and test image collection and image processing diagnostic techniques for rapidly characterizing vegetative parameters needed to distinguish between sustainable and nonsustainable impacts of military training and testing.

(2) Reduce the amount of downtime and off-limit areas imposed by rehabilitation/mitigation activities by identifying critical stages of habitat degradation and focusing resources to extend resiliency of training areas for longer periods of time.

(3) Develop and evaluate the cost-effectiveness of new rehabilitation and restoration techniques for short-term and long-term sustainment needs in desert ranges.

(4) Demonstrate diagnostic and emerging restoration technologies at Fort Irwin that will reduce the life-cycle costs and time for rehabilitation, and ensure compliance with federal environmental regulations.

(5) Provide a suite of diagnostic and restoration tools applicable to military testing and training in other desert locations and non-desert ranges and to facilitate models currently in use or under development.

The technologies being evaluated and tested are divided into two principal areas: (1) diagnostics, and (2) restoration techniques. The diagnostic techniques are further divided into image collection and image processing techniques.

3.0 PROJECT COORDINATION AND PLANNING

3.1 Technical Team

The research team will include researchers and advisors from government, universities, and private industry. Collaborators include DOE/Nevada Operations Office (NV) – Bechtel Nevada (BN), DoD – Fort Irwin, Center for Ecological Management of Military Lands at Colorado State University (CSU), U.S. Army Construction Engineers Research Laboratory (USACERL), California State University Dominguez Hills (CSUDH), DOE/Yucca Mountain Office – Science Applications International Corporation (SAIC), and Weber State University – Applied Ecological Services, Inc. (AES).

Key investigators include:

Dr. Kent Ostler of BN, will serve as the Co-Principal Investigator for the Project. He has over 20 years of experience in the field of reclamation and arid land ecology and has designed and implemented numerous reclamation projects and evaluated reclamation techniques throughout western North America. He has been the project manager for DOE/NV's ecological monitoring and compliance programs on the Nevada Test Site (NTS) for the past nine years. He has directed research work on reclamation at NTS and other DOE sites in Nevada and California, and has authored numerous reports from these studies. He understands management and cost control techniques for large, multidisciplinary and multi-site projects. His primary responsibility will be to coordinate the various participants and advisory groups. He will track progress and ensure that project milestones and deliverables are met. BN organizes and executes all work on a project basis and has excellent project management software (scheduling, costing, critical path) and support.

Dr. Dennis Hansen is a plant ecologist with BN who will serve as Co-Principal Investigator for the project. He will develop and evaluate rapid assessment of vegetation structure using video and remote sensing techniques with applications of digital image processing software. He has extensive experience as a remote sensing and revegetation specialist. He has prepared a number of user's guides for revegetation of disturbed lands, including projects for the Office of Technology Assessment (U.S. Congress). He has organized and conducted several international workshops in revegetation and trained federal and state government organizations in monitoring and revegetation techniques. He has a working knowledge of the ecology of many vegetation types in the United States, having worked in more than 18 states from the arctic to the tropics.

Dr. David Anderson is a reclamation specialist with BN and has extensive experience in implementing large-scale (200 to 1,000 acres) reclamation projects (e.g., revegetation of lands disturbed by oil and gas development activities on the Naval Petroleum Reserves in California) in low-rainfall (< 5 inches/year) areas. He has also designed and established numerous reclamation trial plots. He will be responsible for the implementation of the various restoration technologies that will be tested at Fort Irwin. Dr. Anderson has been involved in the reclamation

of disturbed lands at either a research or operational level for the past three decades. Research has focused on establishment of plant species in harsh growing conditions, effects of various revegetation techniques on plant performance, irrigation strategies for remote locations, reestablishment of biotic soil crusts, and control of fugitive dust using chemical soil stabilizers as part of the reclamation process.

Dr. Steve Warren with the Center for Ecological Management of Military Lands at CSU will provide support in linking LCTA and erosion control models with data derived from the restoration tests conducted during this effort. Dr. Warren is one of the original developers of the Army's LCTA program. He was instrumental in developing the links between the LCTA program and the erosion models that form the basis of ATTACC model. His participation in the proposed project will ensure that the data derived from the monitoring techniques are compatible with existing erosion models and those that are currently under development with the Strategic Environmental Research Development Program (SERDP) funding at the U.S. Army Construction Engineering Research Laboratories. Dr. Warren is also one of the primary developers of the Land Rehabilitation and Maintenance (LRAM) component of the Army's ITAM program. He is the Project Leader of the Arid Land Management Capability Package and is involved in cutting-edge research regarding the reestablishment of cryptogamic soil crusts that are critical components of many arid ecosystems. This knowledge and experience has contributed to the proposed restoration techniques and model applications.

Dr. Christopher Lee is an Associate Professor and Chair of Earth Sciences at CSUDH and an adjunct Assistant Research Scientist at the University of Arizona. He has specialized in remote sensing and Geographic Information System (GIS) applications in arid environments for the past 14 years and is a former Fulbright Senior Research Scholar to Egypt. Dr. Lee has been working at Fort Irwin for the past several years developing techniques to map disturbance using satellite data. He has also collected extensive ground truth data from various locations at Fort Irwin. He will coordinate satellite data with the new diagnostic tools developed during this project.

Dr. Gene Capelle with BN's Special Technologies Laboratory (STL) n Santa Barbara, California, will be responsible for the testing of the Laser Induced Fluorescence Imagery (LIFI) technology. Dr. Capelle's specialty is lasers and spectroscopy, specifically as applied to remote sensing problems. Since 1995, he has been a principal investigator of research investigating plant vitality as monitored through optical signatures from the plants to assess the presence or absence of certain nutrients or contaminants. Under this project, measurements are being made to characterize the responses of various plant species to selected nutrients as well as to chemical contaminants; from this information optical remote measurement techniques are being identified and developed.

Ruth Sparks, with Chariss Corporation, is located at Fort Irwin and directs the ITAM program at the Army's National Training Center. As the LRAM coordinator, her efforts have been directed toward the management of military training lands. Since March 1996, 15 erosion control and revegetation projects have been implemented to repair damage caused by training activities and promote a safe training environment. She is currently developing a plan for integrating long-term biological monitoring data, remote sensing, soils maps, training scenarios,

and other data layers within a GIS framework to direct LRAM activities. Ms. Sparks will provide coordination for plot location, maintenance activities, and field work in relation to military training activities for the demonstrations and studies to be conducted at the National Training Center.

Mickey Quillman is with the Directorate of Public Works at Fort Irwin and will be the principal contact for activities that will occur at the National Training Center. He has been at Fort Irwin for the past four years, where he serves as Natural Resources Manager, with responsibilities for Threatened and Endangered Species, Pest Management, and Natural and Cultural Resource Compliance.

3.2 Technical Advisory Team

Dr. Cyrus McKell is currently President of AES. He is the former Dean of the school of Biology at Weber State University; Committee Chair, National Academy of Sciences (Revegetation Semi-Arid and Marginal Lands); and Director of the Institute for Land Rehabilitation at Utah State University. Dr. McKell has extensive reclamation experience in deserts of the world and has worked at numerous military ranges evaluating revegetation problems. He is author of several textbooks on the biology and utilization of shrubs (McKell, 1989) and technical publications setting industry standards for many revegetation techniques used in the western United States. Dr. McKell is responsible for chairing the Technical Advisory Team of restoration specialists and the Reclamation Workshop.

Six other specialists in the areas of remote sensing, reclamation, and arid land ecology were identified and invited to serve as technical advisors for the project. Dr. Merrill Ridd from the University of Utah and Dr. Charles Hutchinson from the University of Arizona's Office of Arid Land Studies are both well-known experts in remote sensing, particularly in satellite images. Dr. Kathyn Thomas with the University of Northern Arizona has done vegetation sampling and mapping in the Mojave Desert using both aerial and satellite images. Dr. Von Winkel, with SAIC (the M&O contractor the DOE's Yucca Mountain Project), assisted in coordinating the reclamation workshop and serves on the Technical Advisory Team. Dr. Winkel is currently serving on the Mojave Desert Land Reclamation Task Force. He is in charge of the reclamation program at DOE's Yucca Mountain Project and has done numerous reclamation trials in the Mojave Desert. Steven Monsen, with the U.S. Forest Service Shrub Science Laboratory, has been conducting reclamation research throughout the western U.S. for the past 25 years. He is a recognized expert in the area of reclamation. Dr. Richard Gebhardt with the U.S. Army Construction Engineers Research Laboratories in Champaign, Illinois, is familiar with the ITAM program and vegetation parameters that are needed as input to models developed for that program. He also has numerous contacts with other defense facilities and will be helpful with the transfer of technology developed during this project.

A project organization chart (Figure 1) outlines the various project tasks and identifies key responsibilities.

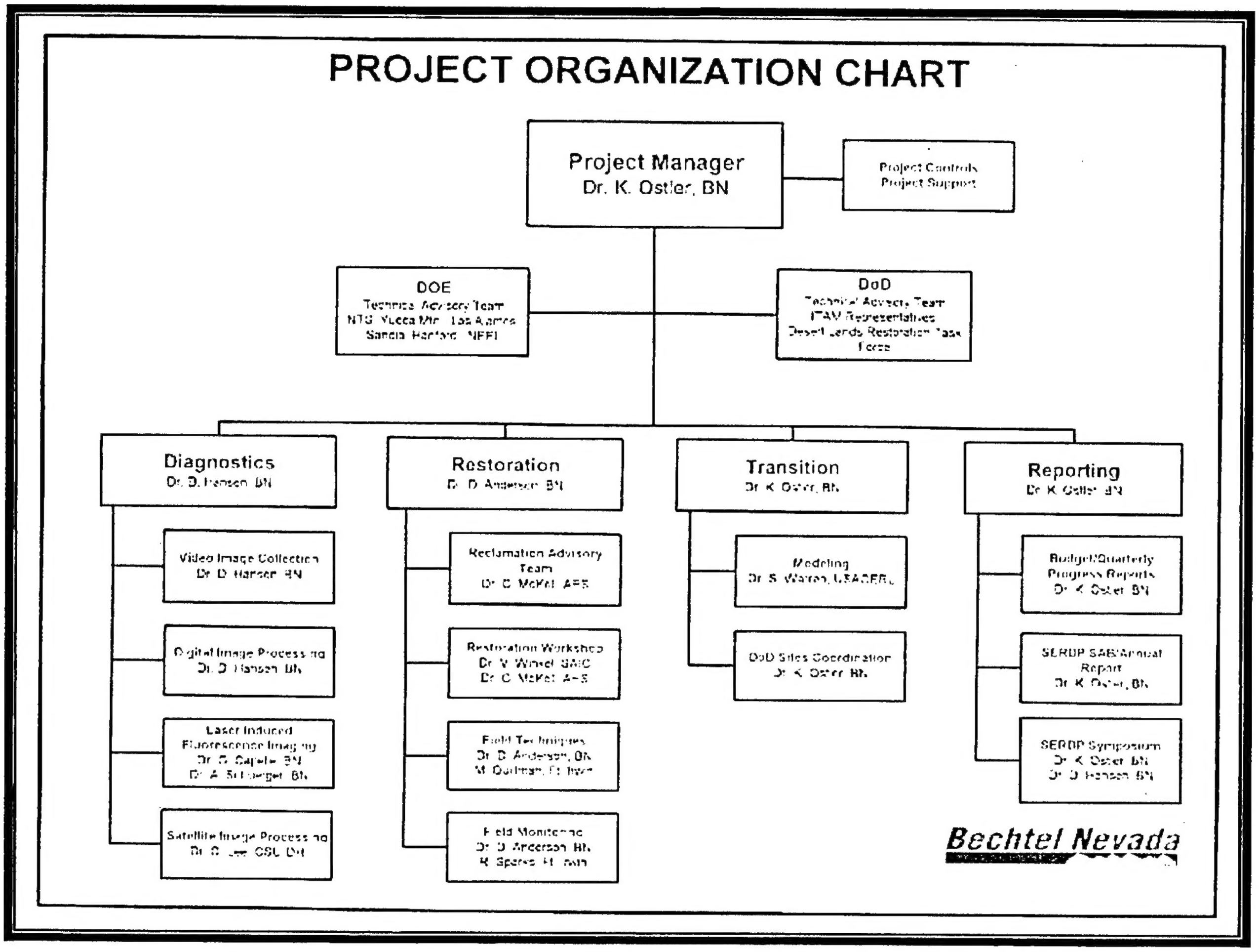


Figure 1. Project Organization Chart.

1.3 Management Plan

One of the key aspects of managing a large research project such as this one is to have a management plan that outlines tasks and objectives, identifies key responsibilities, provides schedules for key deliverables, and provides detailed budget and cost accounting. The first task for this project was to develop a detailed management plan. With the assistance of key project participants, the project tasks, subtasks, goals and objectives, and deliverables were developed, along with schedules and milestones. This information was compiled into a draft management plan that was sent to the Technical Advisory team for review and comments. Review comments were discussed at the August Technical Advisory Team meeting in Las Vegas. Comments were incorporated and the management plan was completed.

This management plan not only serves as a framework for this project, but it is also a living document that will continue to be refined, as needed, to respond to research results and new improvements in technology. Each year, the plan will be reviewed as modified as needed.

4.0 DIAGNOSTIC TOOLS

An essential component of monitoring to determine the spatial extent and degree of military impact is the ability to accurately assess site changes through time as training areas undergo normal use under varying climatic conditions. Historically, monitoring techniques have been primarily limited to expensive, labor-intensive ground collection of data such as plant canopy cover by line-point or line-intersect methods, and plant density by quadrat sampling techniques. Additionally, accessibility to the range by field biologists has been limited at many sites to only one week each month due to intensive military training exercises, making it difficult to obtain sufficient field data during narrow windows of opportunity.

Alternatives to ground-based monitoring techniques are those that focus on remote sensing. Traditionally, these techniques have used satellite imagery as a means of capturing and assessing vegetation conditions at a landscape-size area or scale. Information such as the intensity of a particular wavelength of light or ratio of wavelengths from individual area units of the satellite image (known as pixels) are then statistically correlated with data taken on the ground (e.g., canopy cover or plant density). Pixel size for most satellite images ranges from 10^2 meters to 30^2 meters, which further restricts the usefulness of this technique because most shrubs are often less than 1 square meter in size. This method is useful in areas where ground cover of vegetation is relatively high (e.g., > 30 percent cover) and impacts to the vegetation result in spectral changes that are detectable in the digital images (Falkner, 1995). Such conditions are common for agricultural lands, grasslands, and forest areas, but are less useful in desert areas where plant canopy cover is often less than 10 percent and may be as low as 1 to 2 percent following intensive training impacts such as encampment.

Large-scale ecoregion management approaches have relied upon satellite imagery such as LANDSAT multispectral and thematic mapper (TM), and SPOT (Satellite pour L'Observation de la Terre) panchromatic/multispectral images (Plumb and Pillsbury, 1986). For example, at Fort Irwin, California, the use of this approach has been successful in identifying broad disturbance patterns attributed to military training impacts over time (Lee, 1995). Project scientists selected Fort Irwin for development of new diagnostic tools because it is one of the largest training facilities and it is where previous studies have provided a sound foundation of biological, modeling, and remote sensing information. Proposed work was designed to be built on this foundation of existing site information.

Despite the usefulness of conventional remote sensing techniques, data deficiencies still exist in applying these techniques to assess the sustainability of training impacts. The deficiencies are associated with the inability to obtain additional levels of detail needed to determine essential characteristics of the vegetation such as shrub cover, density, and species composition. These parameters are needed to establish recovery thresholds where increasing costs and rest-rotational use patterns may restrict short-term use in order to sustain long-term testing and training.

Because training impacts are ongoing at most military training areas and precise location of these impacts are somewhat unpredictable, a method for rapidly monitoring condition of soils and

vegetation is needed to determine the condition of vegetation, assess its resiliency to training impacts, assess impact severity, and to direct maintenance activities. A method for rapid capture of field data is required. Such rapid detection methods are being developed as part of this project using aerial photography and hand-held digital cameras to record selected ground details. These techniques can utilize permanent transects or photo points to assess year-to-year trends and to be compatible with current sampling formats in LCTA. The focus of this research project is to develop techniques that bridge the gap between the labor-intensive and costly ground collection techniques and remote sensing techniques using satellite imagery which is less expensive, yet less precise in detecting vegetation change. To facilitate the discussion of diagnostic tools, results are divided into two topics: image collection and image processing.

4.1 Image Collection

Information about vegetation, soils, and desert pavements on the ground can be captured by photographic imaging techniques. This is most commonly done using standard photographic methods such as aerial photographs taken from an airplane. Various cameras and films are used to enhance photographic details. Fast camera lenses that permit rapid capture of images reduce blurring from aircraft movement, and chemically coated lenses reduce scattering of photons of light or wavelength changes. Integration with global positioning satellites (GPSs) and aircraft instrumentation also enable post-image processing to correct for aircraft movement between frames for georectification. Film speed, wavelength sensitivity, and emulsion grain-size influence the quality of the resulting image. The constant improvement in cameras, lenses, and films provide a means of improving image collection techniques.

Film may be processed as positive or negative images. The advantage of positive images is that they can be more readily interpreted by the technicians without a loss in image quality. Negative film is often printed as positive photographs and suffers slight degradation in the enlargement process. The degree of degradation is dependent on the quality of the lens of the enlarger and the photosensitive quality of the photographic paper used to print the image. Fortunately, considerable research has occurred during the past 50 years to minimize image degradation.

Photographic images either as positives, negatives, or paper prints can be scanned using photosensitive instruments called scanners to create digital images that can be stored, manipulated, and analyzed. Scanners use a light sensor head that measures information about light wavelength (usually red, green, blue or cyan, yellow, and magenta) at predetermined units of area referred to as pixels. Image size or resolution is usually reported as the number of pixels per square inch. Generally speaking, the higher the number of pixels per square inch, the greater the mechanical resolution of the digital image. It is also possible to alter the number of pixels by interpolation. This is a mathematical method of increasing or decreasing the number of pixels in an image in a process called "resampling." Large numbers of pixels require more storage space and processing time than small numbers of pixels in an image. It is usually advantageous to limit the number of pixels to the minimum needed to properly resolve the details needed for photo-interpretation.

There are two basic types of scanners: flatbed scanners and film scanners. The flatbed scanner is the more common scanner and consists of a sensor head that moves within an enclosed box covered by a thin, flat piece of glass. The photograph or film lies flat on the surface of the glass. This type of scanner is the least expensive ($1,000 to $2,000), but suffers from slight image degradation by light scattering from the glass. Scanner resolution ranges from about 1,200 to 2,400 dots (pixels) per inch (dpi). The second type of scanner is less common and consists of a sensor head that moves directly across the film or photograph without any glass between the sensor head and the film. The film may also be mounted on a drum that is spinning at high rates with a stationary sensor head. Scanner resolution ranges from about 2,400 to 4,800 dpi) and provides the highest quality of digital image. A disadvantage of the film scanner is that it is expensive ($10,000 to $20,000) for large-format films (e.g., 9 inches × 9 inches), although there are some less-expensive film scanners ($500) for 35-mm film sizes. Because of its high resolving capabilities, dust and dirt on the film and lens are more of a problem and extra care must be taken to eliminate artifacts resulting from such contaminants.

4.1.1 Satellite Imagery

Satellite imagery does not use photographs like conventional aerial photography, but rather consists of remotely sensed data from light sensors and filters that scan a precise area on the earth's surface and store the data as numerical data. Data can subsequently be printed as an image or manipulated and analyzed mathematically. The U.S. satellite LANDSAT and the French satellite SPOT are the two most commonly used satellite images. They have data in multiple bands or wavelengths, consisting of panchromatic (black and white, mainly for resolution) and multispectral (color for image composition) bands. The major limitation in the use of the imagery is in the very large pixel size. Pixel sizes are usually 30 meters × 30 meters for color bands and 10 meters × 10 meters for black and white bands (SPOT data only). Satellite imagery is relatively inexpensive, but has limited time intervals and scale, and may have reduced value because of cloud cover. Such imagery is used in research involving landscapes and is usually considered to be a relatively low-resolution image compared to aerial photography taken by fixed-wing aircraft.

Newer and higher-resolution satellite imagery is anticipated to be available in the near future. The IKONOS 2 was launched successfully on September 24, 1999, and has a 1-meter resolution panchromatic sensor and a 4-meter resolution multispectral sensor, the highest spatial resolution available from a commercial imaging satellite. This research focuses on use of this new imagery and correlation of satellite pixel data with higher-resolution data. The analyses of satellite imagery data is based on previous work at Fort Irwin, California. Research to develop disruption classification techniques at Fort Irwin was conducted by CSUDH from 1994 to 1996 (Prigge and others, 1998). They used LANDSAT TM images to give a preliminary statistical measure of disruption assessment. Their goal was to apply disruption classification techniques of their 1994 research to more recent 1996 imagery and thereby permit comparison of disruption levels for the years 1993 and 1996. In addition, the 1996 classified imagery gave a more recent product for accuracy assessment for mapped disruption levels through field checking.

The goal of the CSUDH's past research (1997) was to refine the 1996 disruption classification through ground-based checks against 1996 disruption maps. Albedo maps were produced and attempts to appraise the usefulness of the technique for future statistical and temporal analysis was reported. The map was generated using prepublished pre-launch gains and offsets to convert TM digital numbers to exoatmospheric reflectance in percent. This function used the satellite digital counts (from 0 to 255) to approximate at-satellite reflectances of individual image picture elements (pixels) by correcting for sensor gains and offsets, solar irradiance, and solar zenith angles. Figures 2 and 3 are examples of mapping by CSUDH.

Figure 2. 1999 Thematic Mapper imagery taken of the Central Valley Corridor at Fort Irwin.

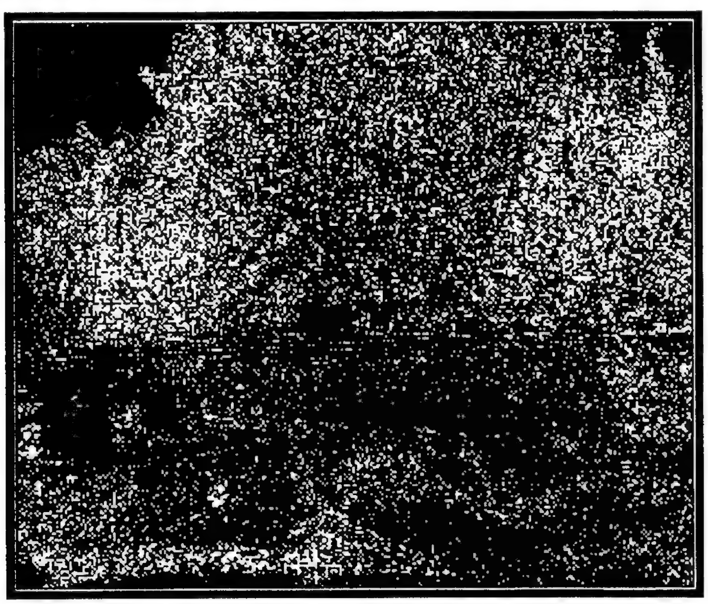


Figure 3. 1999 Disruption map of the Central Valley Corridor. Black areas are mountains, blue areas are lightly disturbed, yellow areas are moderately disturbed, and red are heavily disturbed.

4.1.2 Aerial Photography

Research efforts in 1999 focused on image collection. The objectives of the first year's research (1999) were to make a collection of useable images of Mojave Desert vegetation and identify image parameters such as pixel size and spectral band information (hue and intensity) that are most correlated with vegetative parameters. During the first stage of the project, a collection of photographic images (digital and film images) was assembled from various Mojave Desert environments using different cameras, films, filters, and scales that can be used to evaluate the proposed diagnostic techniques. Once image requirements for high correlation of image parameters with vegetative parameters are established, then quantification of the vegetation can begin in the year 2000. This will permit identification of individual plants and to distinguish species and other vegetative spatial parameters (clumping versus micro-site distribution) and abiotic (desert pavements, calcrete).

It was determined that most of the existing imagery at military training centers in arid lands is at a scale of about 1:24,000 (i.e., one inch on the film equals 24,000 inches on the ground) or smaller where only very large trees and a few large shrubs are visible and distinguishable. At these scales, spatial distribution patterns of vegetation is limited or impossible. At higher photographic image scales such as 1:4,000 or 1:2,000, detection of spatial distribution patterns, cover, and density are possible. It is anticipated that higher-resolution imagery will be obtained during the fall of 1999 and early part of 2000.

New project imagery at Tonopah Test Range (TTR) in Nevada was obtained in July 1999 (photo scales of 1:4,000, 1:8,000, 1:16,000, and 1:24,000). Data from this imagery will be correlated with ground truth surveys (also in July 1999) to provide a means of comparing traditional methods of data acquisition and accuracy with those obtained through image analyses. Aerial imagery (conventional color photography and multispectral data) was taken of ground plots in five major plant communities along an elevational gradient (a playa bottom, up and over a mountain top). Traditional vegetative data (e.g., species composition, cover, and density) were taken at these plots and will be compared with image analyses of photos taken at several altitudes to provide different photo scales. These data were collected in the summer of 1999 and will be analyzed during the winter of 2000. Additionally, new aerial imagery will be taken concurrently with vegetative surveys on revegetation test plots once new plants have established sufficiently to be detected in the aerial photographs.

Existing historical images have been obtained from other SERDP projects (CS-1098) or from DoD and DOE installations like the NTS (Figure 4; photo scales of 1:2,000, 1:4,000, 1:8,000, 1:16,000, and 1:24,000), Fort Irwin (photo scale of 1:24,000), and Yuma Proving Grounds (YPG) (photo scale of 1:24,000).

Preliminary attempts in 1999 to evaluate these images for spatial patterns and cover and density in steep mountains have been encouraging. For example, project scientists have been able to

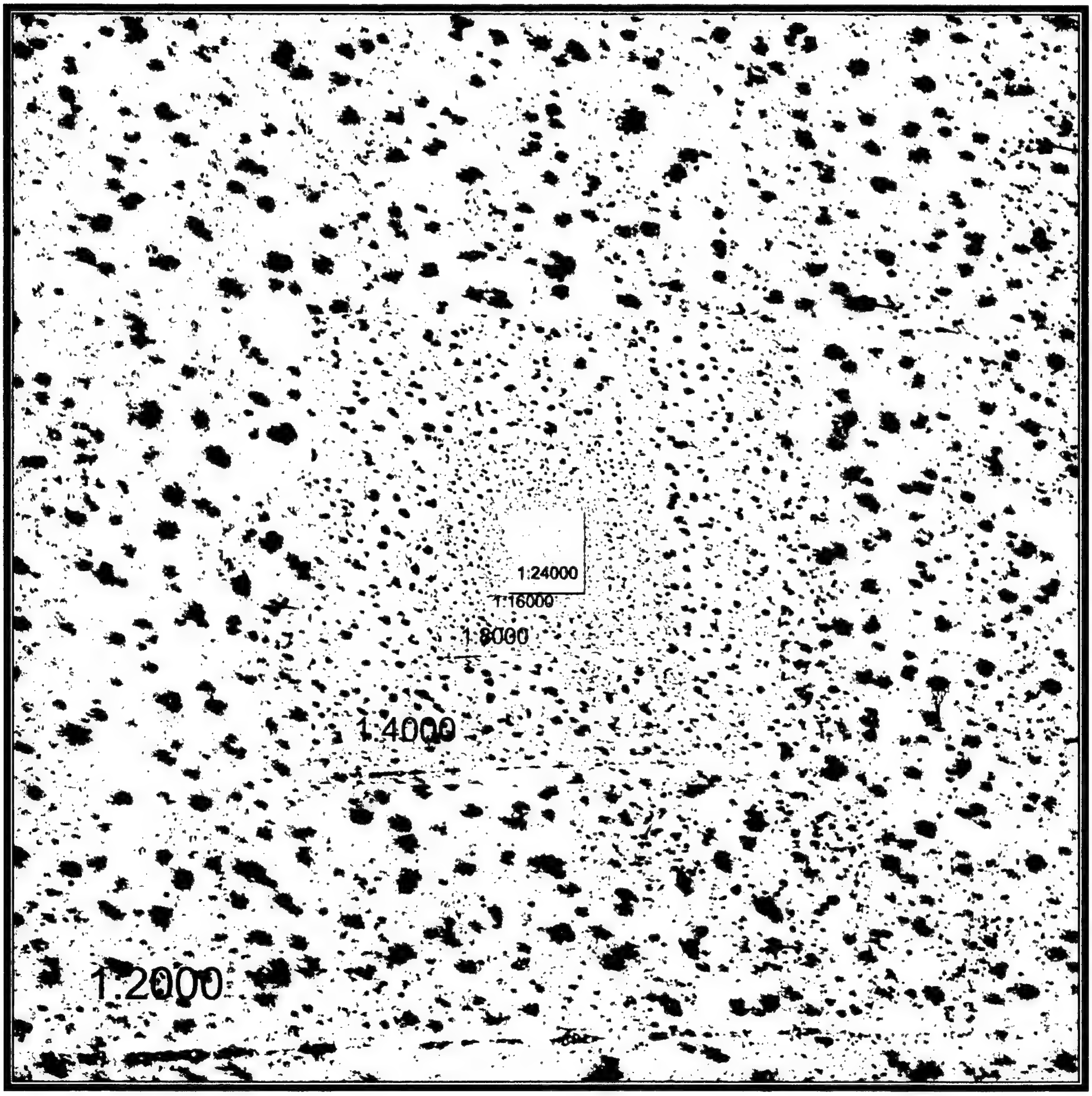


Figure 4. Examples of vegetation details of the same area at different photo scales. Aerial photos are of Mojave Desert vegetation on the NTS, Nevada.

show spatial distribution patterns of vegetation at the base of alluvial fans covered with desert pavement and along drainage ways at YPG. In steep mountainous areas of the TTR, spatial patterns of increasing cover and density of trees and shrubs are detected along elevational gradients and drainage ways where soils vary in depth and moisture holding capacity. At the NTS, the most detailed images have revealed considerable information about spatial patterns of vegetation (*Figure 3*). This work will be accelerated as soon as even more detailed images are taken using cameras mounted on helium-filled balloons, kites, and helicopters and made available to the project.

4.1.3 High Resolution Imagery

Availability of aerial photography is often limited on military testing and training ranges because of limited accessibility, infrequency of flights, and higher cost compared to satellite imagery. Photographic coverage needed for monitoring selected areas, testing hypotheses, and image processing research does not always necessitate having photographic coverage over the entire range, thereby creating a need for higher-resolution imagery of smaller areas. This high-resolution imagery can be obtained through several techniques which involve mounting cameras to helicopters, helium-filled balloons, large kites, and elevated telescoping poles. Each of these data acquisition techniques has its benefits and limitations.

During 1999, aerial photographs were taken of Mojave Desert vegetation at Nellis Air Force Base, Nevada. Images were taken with Nikon and Hasselblad 35-mm cameras, and two types of digital cameras. Imaging elevations were 150 feet, 250 feet, 350 feet, and 500 feet, with both normal (50-mm) and wide-angle lenses (35-mm). The test location included commercial resolution test patterns (Figure 5) and a gradient of soil moisture within the same photo location to enable the detection and comparison of dry and moist shrubs.

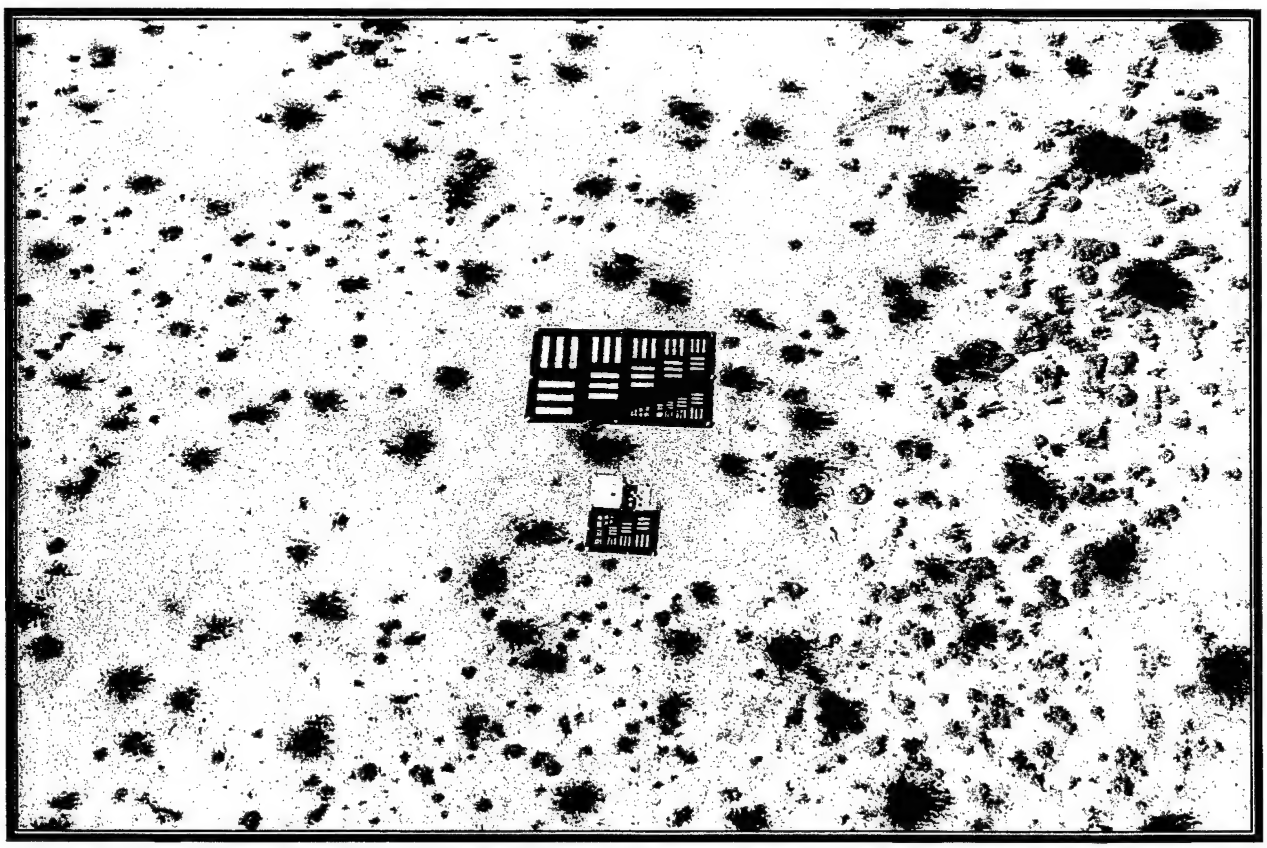


Figure 5. Photo resolution targets and Mojave Desert vegetation near Nellis Air Force Base, Nevada.

Sample photographs taken from a helium-filled blimp (Figure 6), large kites (Figure 7), and an aluminum, telescoping pole (Figure 8) were also obtained to test image processing techniques.

Figure 6. Helium-filled blimp used to obtain aerial photography near Nellis Air Force Base, Nevada.

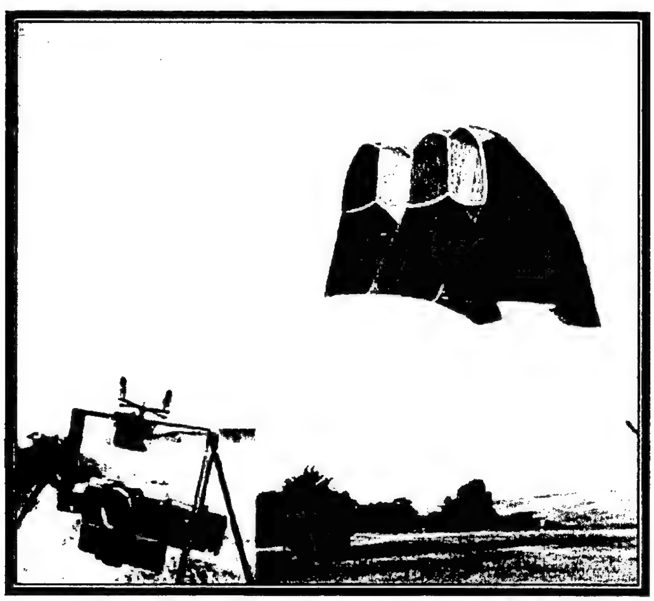


Figure 7. Example of a kite used for acquiring aerial photography.

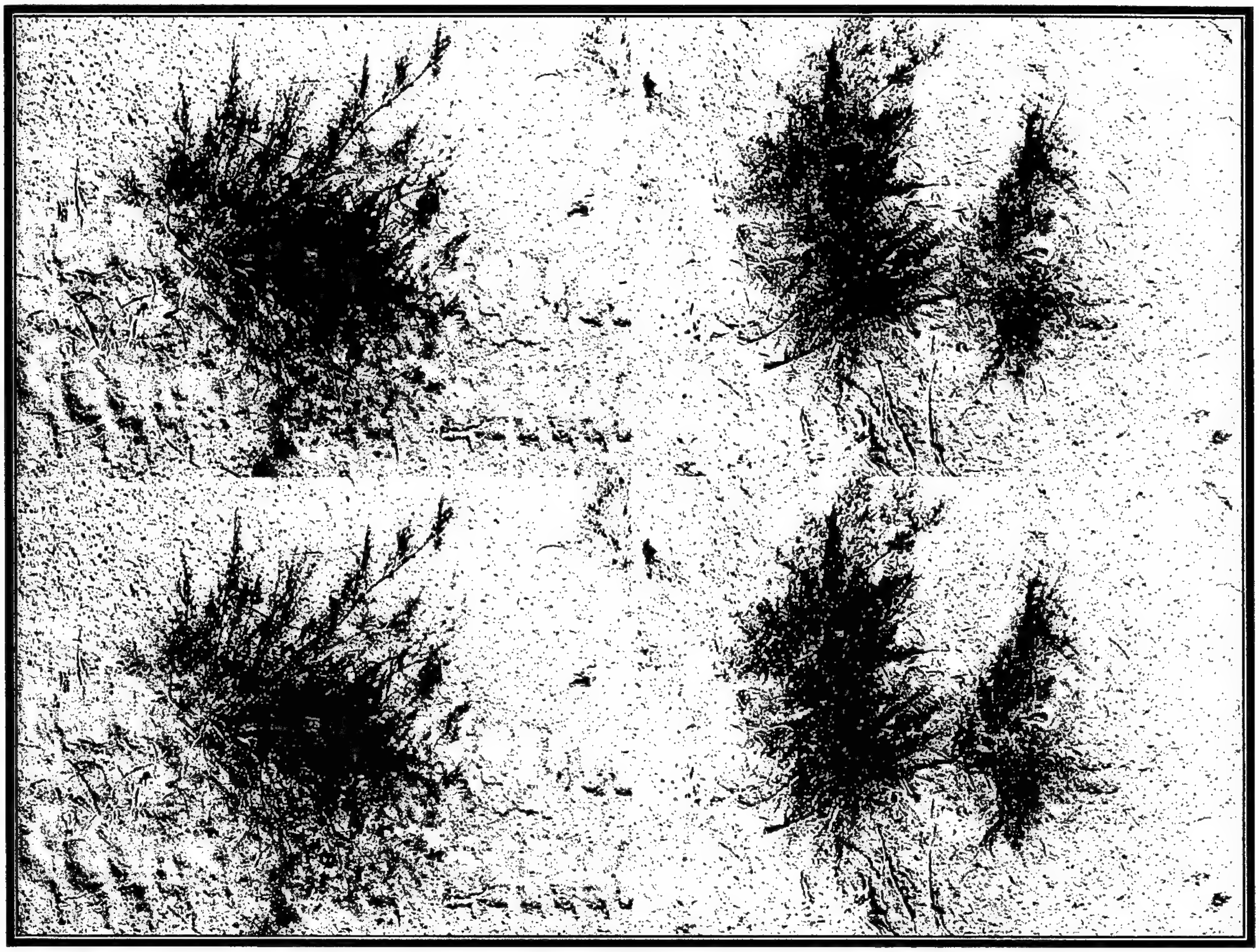


Figure 8. Close-up photography of vegetation using a bipedal tower. Upper pictures show normal (green) vegetation. Lower pictures show detection of vegetation (red) using new photo-processing techniques explained later in the text.

4.1.4 Laser-Induced Fluoroscopy Imagery and Spectroscopy

The use of LIF Imagery and Spectroscopy (LIFS) is being evaluated as a sensor collection and analytical tool to detect vegetation stress in the Mojave Desert. Dr. Gene Capelle from BN's STL in Santa Barbara, California, visited the site at Fort Irwin, received preliminary site safety training, and reviewed site conditions preparatory to beginning field sensing testing. The LIFI will be used in conjunction with other conventional monitoring techniques to determine stress levels in vegetation and the soil.

LIF data were collected from the two most dominant plant species at the National Training Center at Fort Irwin, creosote bush (*Larrea tridentata*) and white bur sage (*Ambrosia dumosa*). Figure 9 shows the equipment during operation. All control electronics, including computers, the laser power supply, etc., were located in a 4-wheel-drive vehicle. A tripod carried the

excitation source (355-nm pulsed laser light source) and detector heads, including an alignment camera, a LIFI camera, and optics for collecting fluorescence light from several fields of view and converting this information into fiber optics (for LIFS); an umbilical containing the fiber optics, as well as electrical lines connected to the equipment located in the vehicle; and a generator (placed away from the electronics) to power the system. Numerous system modifications were made to the laboratory system before taking it into the desert, including lengthening the umbilical, enclosing the multi-channel fiber optic link in a protective sheath, acquiring a generator and UPS (uninterruptible power source) for field operation, adding a compact CCD camera plus a 2.9-inch LCD (liquid crystal diode readout screen to the tripod for accurate system pointing, increasing the laser for improved output and faster data collection.

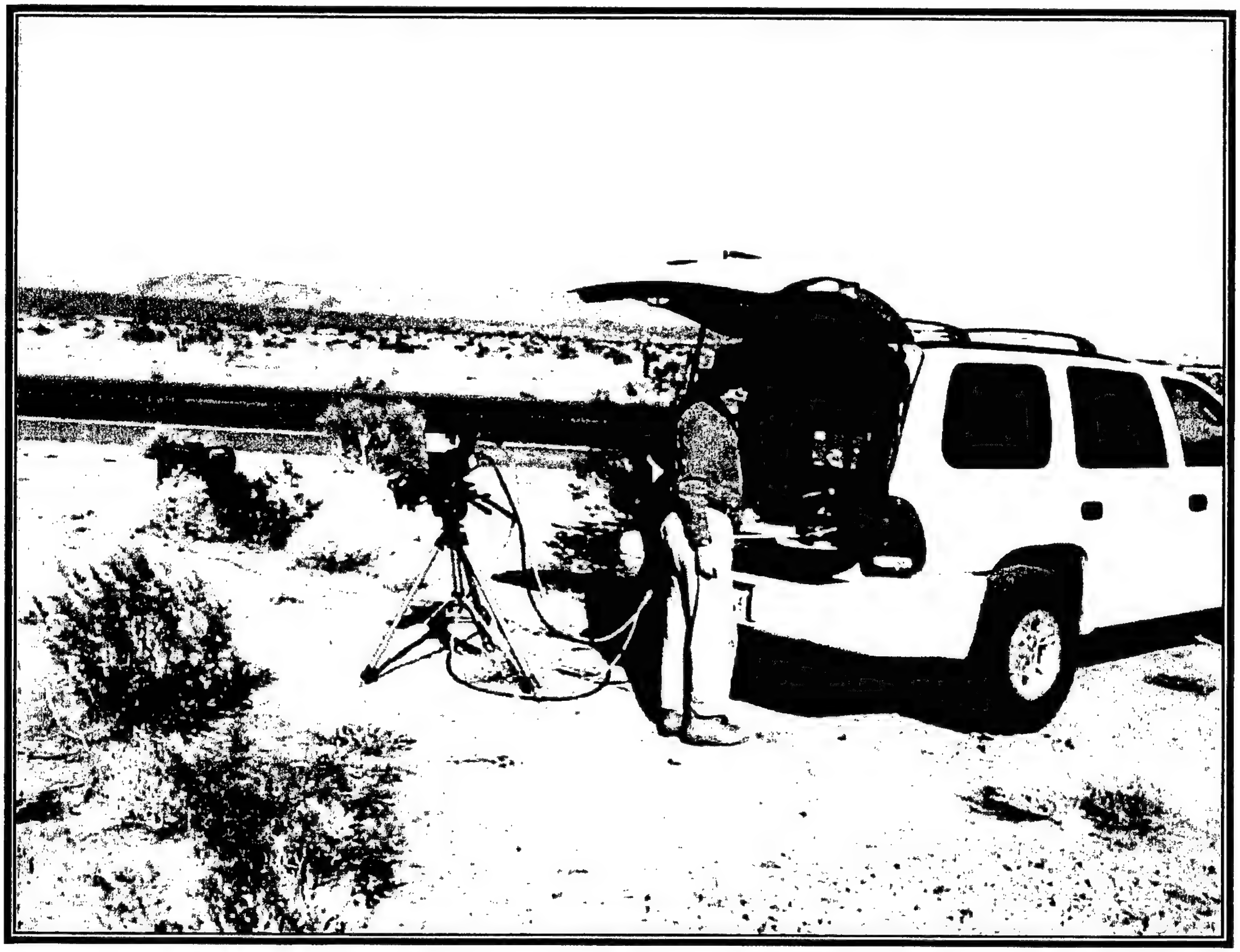


Figure 9. Laser-induced fluorescence gear as used at Fort Irwin site.

The primary measurements on this trip were made with the LIFS system. While this system does not give images, the LIFS system provides reasonably high-resolution (3 nm) spectral analysis of the fluorescence returned from the targeted plants in the 400- to 800-nm band, using two different fields of view. This allows project scientists initially to see spectral changes and to zero

in on the important wavelength regions of the fluorescence spectrum emitted from the target plants, and to fine-tune the LIFI filter bands for future measurements. (LIFI provides images of the fluorescence, but only in four relatively broad spectral bands.)

The purposes of the first field measurements at Ft. Irwin were:

- to become familiar with the fluorescence spectrum of two desert species of plants common to the area and to identify the important spectral regions (for later LIFI work),
- to look for differences in spectral signatures between species,
- to check for consistency and performance of results looking at a two different fields of view (approximately 5.5-centimeter [cm]-diameter and 13.5-cm-diameter spots) and at two completely different regions of the same (visually homogeneous) plant,
- to test the instrumentation in this new field operation scenario, and
- to look for spectral differences between healthy and stressed plants.

Typical standoff for these measurements was 5 feet, and measurements were made at two different fields of view. For creosote bush, measurements were made at two completely different locations on ten "healthy" plants and on ten "stressed" plants. In the case of creosote bush, the "healthy" plants were typically those growing near the road, where the water supply was enhanced by runoff from the road; "stressed" plants were those located away from this zone, where the effect of the dry weather to date was causing water stress, and presumably caused the plants to go into a dormant state. In the case of white bur sage, most of the plants were water-stressed (i.e., very dry, with leaves often falling off upon touch). An exception was near a leaky water tank, where some white bur sage plants were still growing in a non-dormant condition. All field data were collected near the northern end of the cantonment area at Fort Irwin and a nearby water tank southwest of Bicycle Lake.

Specific preliminary LIFS results by species are as follows:

Creosote bush:

- Results from medium and wide fields of view were in good agreement, though not as good as for white bur sage, presumably due to the variation in leaf coverage (and exposed stem area) around the plant.
- Similarly, results collected from the two different areas of each plant were usually in good to excellent agreement.
- Red and far-red chlorophyll fluorescence peaks (normally observed around 685 and 740 nm) were not resolved from each other, but rather gave one broad peak around 710 to 715 nm;

this red peak was quite pronounced in healthy plants, but was subdued and, in some cases, not detectable at all in stressed specimens.

- There was typically more fluorescence emitted from the stressed than from the healthy plants.

- Nearly all of the healthy plants displayed a very pronounced fluorescence peak around 560 nm, but this peak was very subdued to unmeasurable in the plants classified as stressed.

White bur sage:

- Results from medium and wide fields of view were in excellent agreement.

- Red and far-red chlorophyll fluorescence peaks (around 700 nm) were not evident in this species.

- Stressed plants emitted more overall fluorescence (both more intense and spectrally broader peaks) than the non-stressed samples.

- With stressed plants, the fluorescence peak was not only broadened, but also shifted significantly (more than 10 nm) toward longer wavelengths.

Figure 10 shows the typical type of fluorescence signals (uncorrected for instrument response) measured from creosote bush using the LIFS instrumentation: The taller (colored) curve is from a water-stressed specimen and the lower (black line) curve is from a relatively unstressed specimen. In some samples, the difference between the curves was much more pronounced than shown in these two “typical” curves.

Preliminary LIFI data collected during the fall field work had signals strong enough that limited LIFI (fluorescence) images could be collected during daylight hours from both creosote bush and white bur sage. The bandpass of the filters, however, will need to be modified, based on LIFS data. Preliminary results based on this limited number of measurements appear to be encouraging. It can be concluded that, using LIFS:

- It is possible to differentiate healthy creosote bush from healthy white bur sage.

- It will be more difficult, but probably still possible, to differentiate water-stressed (dormant) creosote bush from stressed white bur sage.

- It is possible to differentiate between healthy and water-stressed creosote bush (the fluorescence curve shapes are *very* different [see *Figure 10*]).

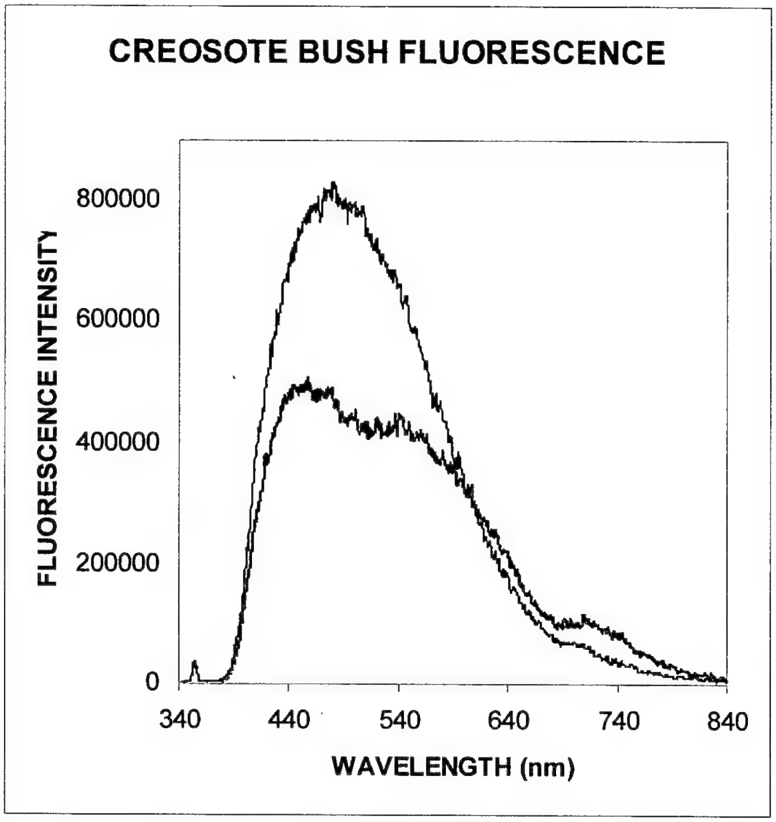


Figure 10. Fluorescence signal from stressed (colored line) and unstressed (black line) creosote bush.

- It will be more difficult, but still possible, to differentiate between healthy and water-stressed white bur sage.

Recommendations for research in the year 2000 include:

- Move LIFS spectral window further to the blue end of the spectrum;

- Optimize LIFI filter set based on this LIFS data, and then collect LIFI data;

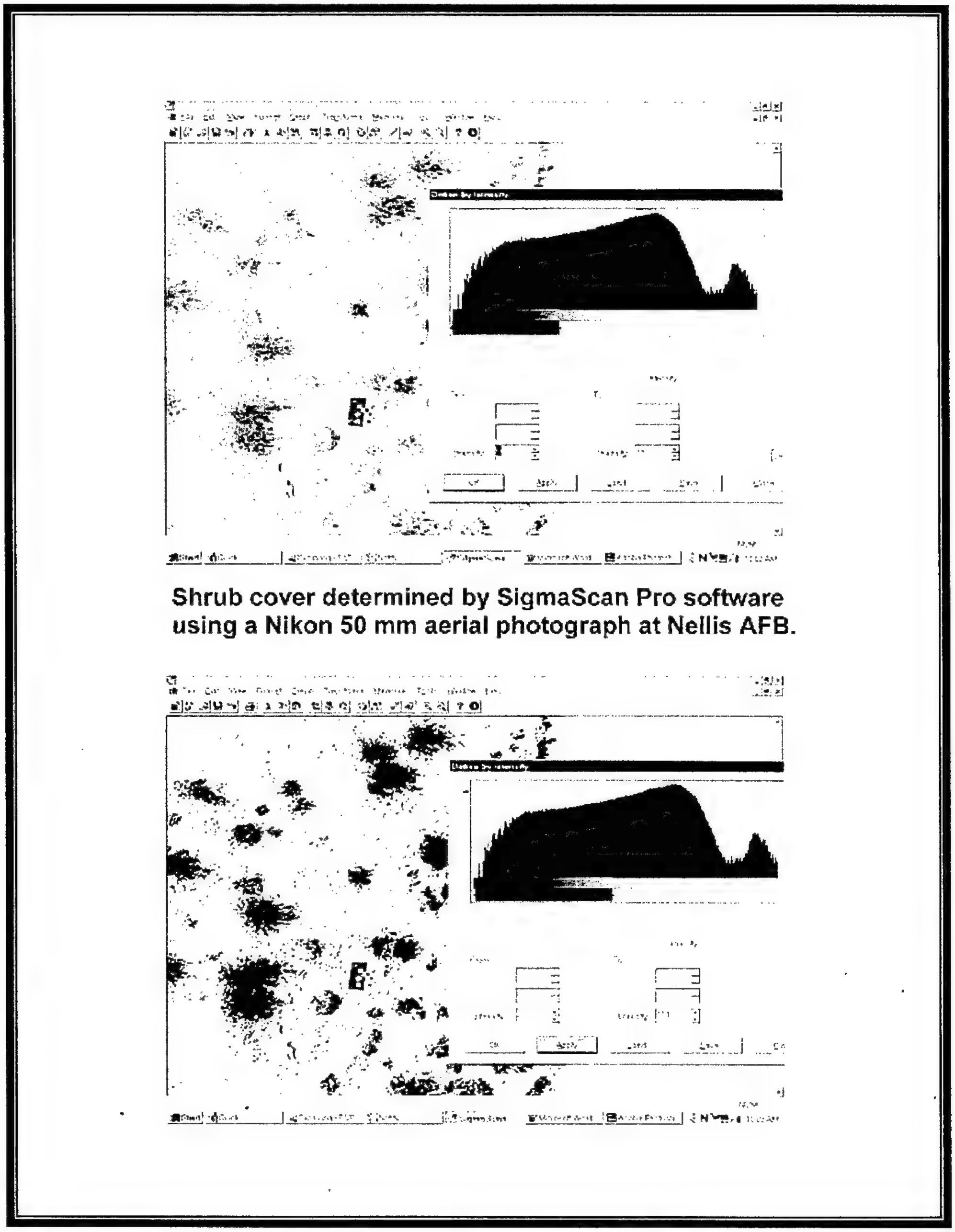
- Incorporate passive reflectance measurements into the suite of measurements to determine if this same information can be determined passively (easier and cheaper than LIF techniques); and

- Increase umbilical length and decrease size and weight of LIF systems.

In addition to healthy vs. water-stressed plants, look at healthy vs. mechanically stressed plants (e.g., plant run over by a tank), and perhaps even water-stressed vs. mechanically-stressed plants.

4.2 Image Processing

Images taken from helicopter or fixed-wing aircraft along selected or permanently marked flight lines can be evaluated using computer technologies to provide rapid assessment of vegetation such as total number of shrubs and cover present in selected areas. For example, using aerial photography of a scale from 1:2,000 to 1:24,000, it is possible to selectively scan a photograph and process the image data to rapidly calculate shrub density and total shrub cover in less than one minute per plot (Figure 11). Conversely, field data collection of the same vegetation may require a team of two people one to two days to obtain comparable data. Additionally, data are analyzed statistically to show size classes of shrubs, a parameter important for assessing impacts from training exercises and shrub demographics. Photographic images taken of Mojave Desert habitat at the NTS (refer back to *Figure 4*, photo scales of: 1:2,000, 1:4,000, 1:8,000, 1:16,000, and 1:24,000), which are comparable to habitat at Fort Irwin, will be used to determine the optimal photo scale and associated error functions.



Shrub cover determined by SigmaScan Pro software using a Nikon 50 mm aerial photograph at Nellis AFB.

Figure 11 Example of measurement of shrub cover using SigmaScan Pro ™ software. Histograms are used to select color band intensities that best correspond to vegetation cover.

Software packages to be evaluated include SigmaScan Pro™, Image Pro™, and Optimas 6.5™. Except for preliminary findings at the NTS, little evidence has been found that this promising method has ever been used to count shrubs and estimate shrub cover collectively or by individual shrub classes. Use of this technique is expected to significantly reduce site evaluation time by several orders of magnitude, while increasing data reliability and application to other desert ranges.

Individual images will be analyzed independently using several software packages that have digital-capture capabilities to quantify selected spectral bands, such as those wavelengths that correspond to living tissues or plant canopy cover. The objective is to develop a procedure for obtaining essential information that cannot be obtained from satellite or high-altitude remote sensing data and to provide sufficient information to extrapolate ground conditions to other similar sites. Based on preliminary findings at the NTS, this technique appears promising.

Digital color images (e.g., Tagged Image File formats, also called Tiff images) are comprised of red, green, and blue bands of data. Each band has pixel values that range from 0 (black) to 255 (white). Each band has slightly different sensitivities to vegetation, dead plant litter, rocks, and soils. Occasionally, it is helpful to use only one band to reduce background "noise" (e.g., small annual plants or litter). For example SigmaScan Pro™ software analyses of the red band detects less litter (i.e., fewer small pixels of red) than the green and blue bands, making it a preferred choice to measure canopy cover and count larger shrubs. Figure 12 compares such values.

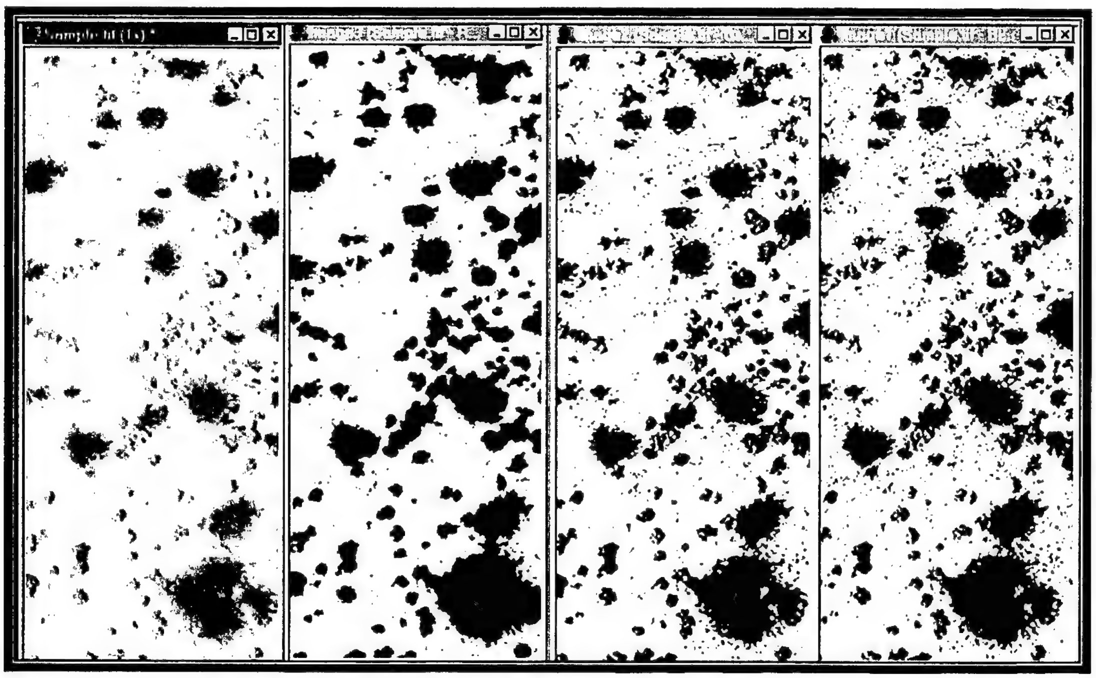


Figure 12. 35-mm color photograph (left) showing creosote and white bur sage near Nellis Air Force Base. The images to the right of the colored photo are red, green, and blue bands of the color image showing delineation of shrub cover (red) from soil (gray).

The use of diagnostics will provide a powerful tool to study patterns of vegetation in arid lands. Examples of spatial patterns that may be detected include: differentiation of random, uniform, and clumped species, relationships of small under-story shrubs to large over-story shrubs or other species; the distribution of shrubs along drainages of different sizes and bed loads; and correlation of species with soil features such as desert pavement, bedrock, alluvium, aeolian

dunes, and subsurface conditions. Any in-depth study of pattern analysis will be dependent on having suitable imagery taken at a proper scale and scanning resolution. Dr. Dennis Hansen is the lead biologist evaluating spatial patterns in the Mojave Desert. It is anticipated that SERDP and ITAM meetings will be used to communicate capabilities and to solicit imagery that can be used to test such patterns. A limited number of images have been obtained and analyzed from SERDP project CS-1098 from a variety of sites (Utah, Texas, and Nevada) to test the utility of the diagnostic tool to help identify ecotones and effects of fire and man-induced disturbances. It is anticipated that more collaboration will occur in subsequent years.

4.1.5 Application Examples

Although emphasis during the first year of the project was to acquire imagery rather than process it, some preliminary analyses were made to test the concept. Most of these analyses were in response to questions about the applicability of the diagnostic techniques to habitats other than the relatively flat Mojave Desert, such as steeper mountainous terrain in the Great Basin Desert or Sonoran Desert. Other applications focused on what could be done with old aerial photographs at military installations whose scale was near the margins of being useful (e.g., 1:24,000-scale photos) due to a lack of photographic details.

4.1.5.1 Tree and Shrub Cover in the Great Basin Desert

SigmaScan Pro™ software has been used to analyze a variety of arid-land plant community types. In addition to Mojave Desert vegetation, it has been used in the Great Basin Desert of Utah to measure tree and shrub cover (Figure 13). The original photo scale was approximately 1:2,400. Utah Juniper *(Juniperus osteosperma)* and big sagebrush (*Artemisia tridentata*) are clearly discerned from background soils in Pinion Juniper habitat in mountainous areas of eastern Utah, about 45 miles south of Vernal.

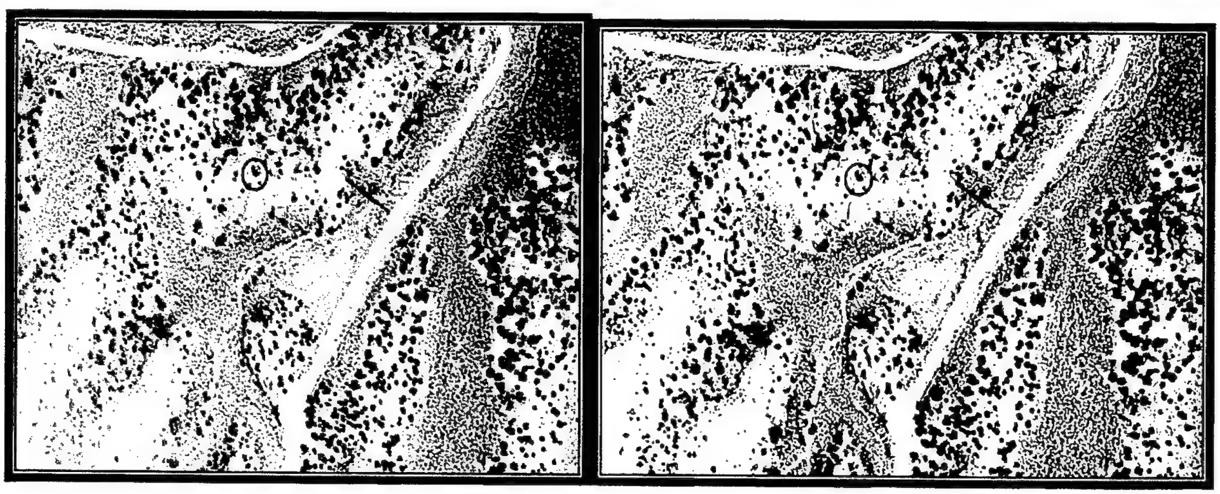


Figure 13. Identification of juniper and big sagebrush cover using color infrared photography (left) and Sigma Scan Pro™ software to distinguish shrub cover (red color, right).

4.2.1.2 Determination of Shrub Cover Differences on North- and South-Facing Slopes

Using aerial photographs at a scale of 1:24,000 at the TTR in Nevada, SigmaScan Pro^{TM} software has been used to measure shrub cover in mountainous terrain. Differences in soil moisture on north- and south-facing slopes are clearly distinguishable (Figure 14). Shrub density and cover are shown to be more abundant on north-facing slopes than on south-facing slopes.

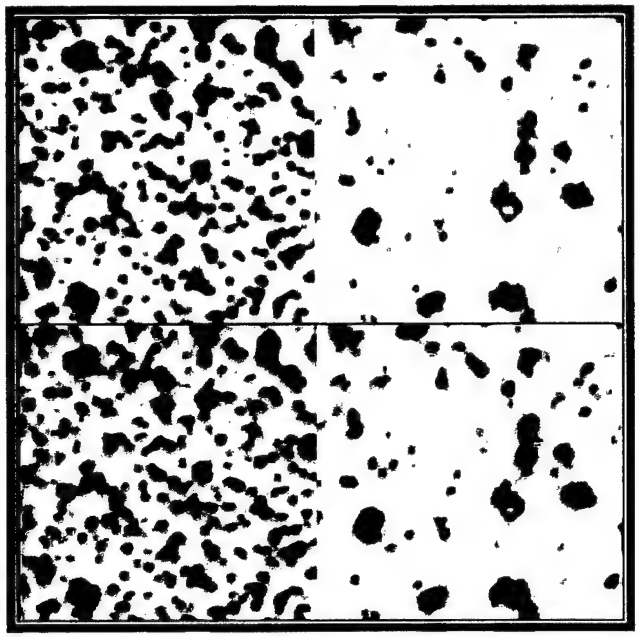


Figure 14. Identification of shrub cover on north- (left) and south-facing (right) slopes at the Tonopah Test Range in Nevada. Red patterns in the lower photographs indicate shrub cover as determined with SigmaScan Pro^{TM} software. Large red patterns are bitterbush (*Purshia* spp.); smaller red patterns are sagebrush (*Artemisia* spp.) and rabbitbrush (*Ericameria* spp.). Light gray areas are soil. Dark gray spots are grasses and forbs.

4.2.1.3 Distinguishing between Desert Pavement and Vegetation

Although it has been determined that 1:24,000-scale aerial photographs are usually the lower limit of resolution for analyses using SigmaScan Pro^{TM} software, analyses of these photographs are of use in distinguishing landscape-size features such as expansive desert pavement and stream channel vegetation dependent on runoff from these rocky surfaces. SigmaScan Pro^{TM} software was used to identify and measure percent cover of desert pavement (red) and stream channel vegetation (green) in the Sonoran Desert at the YPG near Yuma, Arizona (Figure 15). The software permits detected features to be toggled on or off independently. They can be shown separately or together as different colors to help aid interpretation.

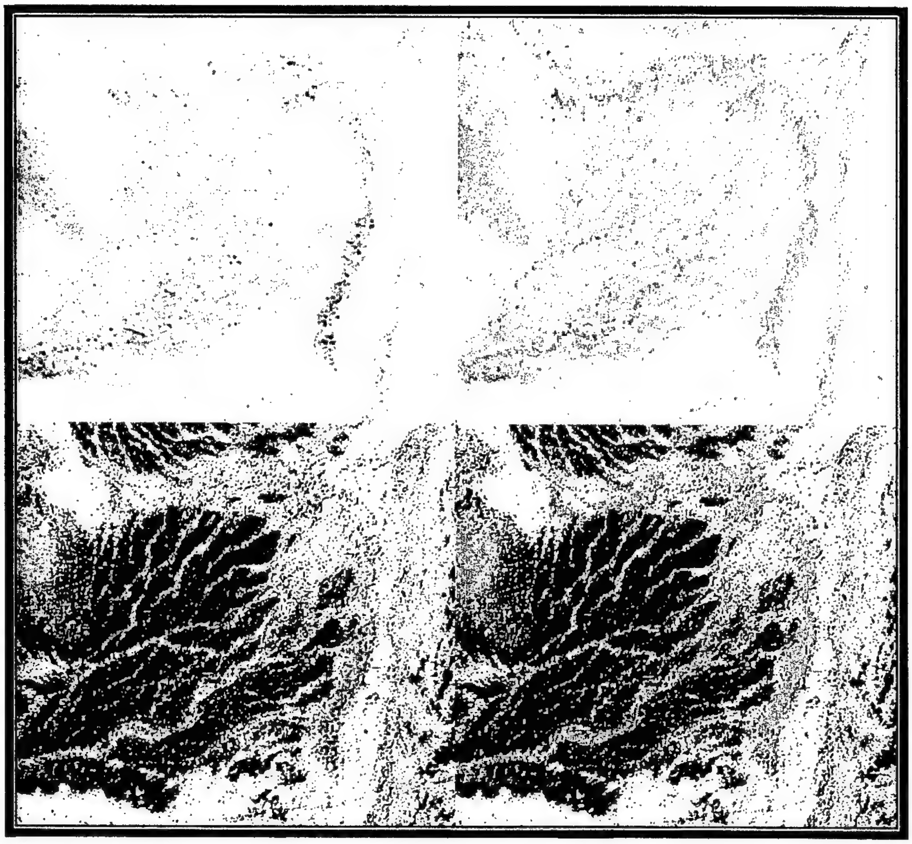


Figure 15. Three color-processed scenes of a 1:24,000-scale natural color photograph (upper left photo) showing an alluvial fan at the Yuma Proving Grounds, Arizona. Red color indicates areas of desert pavement as identified by SigmaScan Pro™ software. Green areas are areas identified as vegetation cover. Colors can be toggled to appear together (lower right image) showing the interrelationship of desert pavement and channels of vegetation.

4.2.1.4 Comparison of Conventional Satellite Image Processing to SigmaScan Pro™ Analyses

SigmaScan Pro™ software was used to compare with statistical regression correlations between conventional satellite image processing as conducted by CSUDH in January 1999 enhanced TM satellite imagery of selected scenes at Fort Irwin, California, to 1:24,000-scale aerial photographs of the same areas taken by BN's Remote Sensing Laboratory in Las Vegas, Nevada. Digital images are shown in Figure 16 to help compare the level of detail available through both analytical techniques. Satellite imagery was not successful at identifying shrub cover at Fort Irwin, while analysis of aerial photographs provided a very accurate method of estimating large shrub cover and details of disturbances due to military training.

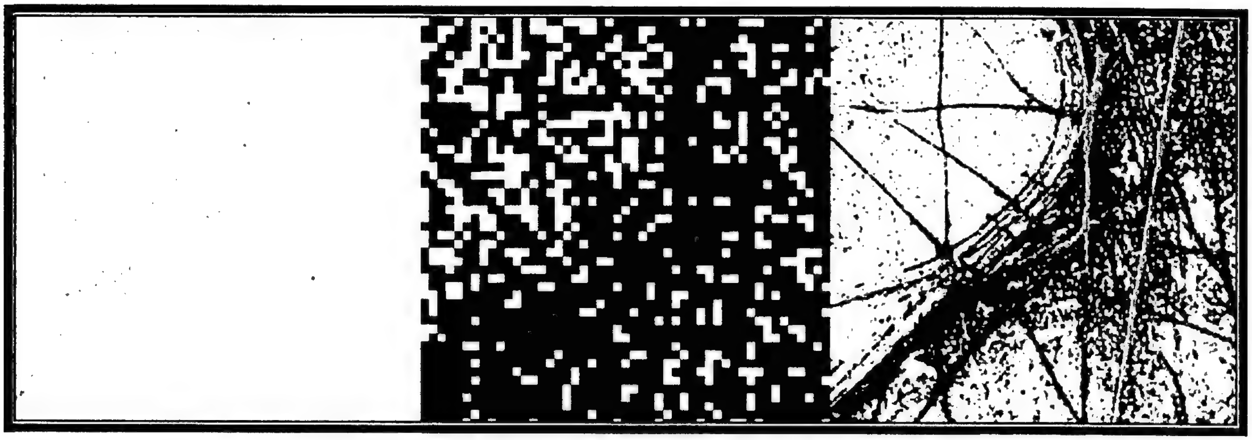


Figure 16. January 1999 aerial colored photo of the "race track" at Fort Irwin (left photo) at a 1:24,000 scale. Image in the middle is from January 1999 enhanced TM satellite imagery. Image on the far right is from our new image processing photo techniques of the same area. Dark blue areas attempt to identify shrubs. Yellow areas identify moderately disturbed areas. Red areas identify heavily disturbed areas. Light blue areas identify very heavily disturbed areas.

5.0 RECLAMATION TECHNIQUES

Successful revegetation of disturbed sites is dependent on site conditions. The major factors influencing success include (1) adequate soil moisture, (2) proper soil substrate conditions (e.g., aeration, nutrients, microorganisms, and organic matter), (3) adequate seed source of adapted species, and (4) implementation and timing of cultural treatments. Revegetation techniques to be tested are those that influence and facilitate these major factors.

For example, moisture-absorbing cross-linked polymers or irrigation can be tested in conjunction with timing of seeding to fully utilize natural precipitation or ensure that soil moisture is comparable to an average precipitation year. Crimped straw mulch stimulates the growth of essential soil microorganisms, breaks up excessive soil crusting, and increases infiltration and soil aeration. Proper fertilization can be tested to provide the proper mix of trace elements from low-cost sources such as humates (naturally occurring organic compounds associated with coal deposits), and surfactants, and macro-nutrients such as phosphorus. Proper selection of nutrients should not encourage herbivory by small mammals, but should increase vigor of persisting vegetation, encourage seed production, and promote the growth of soil microbes that bind soil particles into biotic crusts. In areas where control of blowing sand is a problem, chemical soil stabilizers or biotic crust inoculants may be tested to reduce sand-blasting of newly emerging seedlings and to gain temporary control of blowing dust until vegetation can be established.

The selection of proper equipment to implement revegetation techniques is also essential. Such things as the use of multiple seed boxes to regulate the distribution of seeds with different depth and cultural requirements, and crimping and imprinting wheels can provide the appropriate microenvironments needed for germination, emergence, and seedling establishment. Selection of revegetation-enhancing techniques will be drawn from innovative techniques currently under use and evaluation at NTS and Yucca Mountain (Figure 17) and from other areas of western deserts.

A revegetation workshop was held in August 1999 to evaluate new revegetation techniques, present current research findings of other scientists, and review proposed treatments for the test plots. Selection criteria was evaluated by a panel of reclamation experts to ensure that treatments were (1) practical, (2) low cost and highly efficient, and (3) in harmony with range objectives established for Fort Irwin and/or other desert military ranges. Expert advice was sought from natural resource representatives, ITAM representatives, LCTA experts from military training bases, Desert Lands Restoration Task Force team members, and from a panel of reclamation experts (university and private consultants) knowledgeable in revegetation techniques for disturbed lands.

5.1 Data Gathering Efforts

SAIC personnel used Internet access to conduct a search for current information regarding Mojave Desert and arid-land restoration techniques. One hundred eighty-six individual references with pertinent information were found and documented in Appendix 8.1.

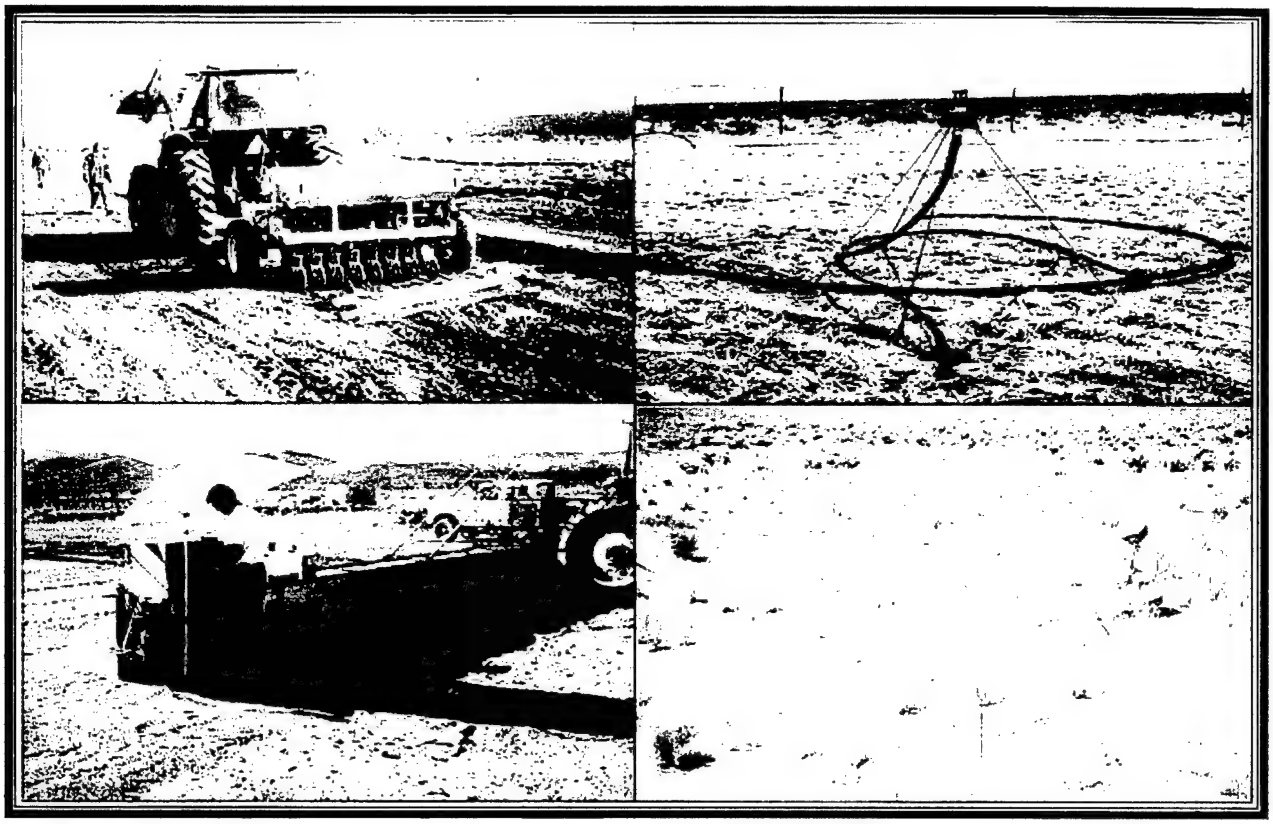


Figure 17. Examples of revegetation techniques used in the Mojave Desert by Bechtel Nevada at the NTS. Photos in clockwise order: (a) seeding equipment with multiple seed boxes, (b) portable irrigation system to simulate rainfall to initiate germination, (c) successful shrub establishment without irrigation demonstrating habitat restoration techniques, and (d) portable wind tunnel equipment to measure particulate movement in revegetated areas.

Most information found consisted of traditional reclamation techniques and methods such as seeding, transplanting, irrigation, and mulches. Other, less traditional methods described (which reportedly improve reclamation success) included soil pitting, vertical mulch, imprinting, synthetic soil amendments, and inoculation of the seedbed with mycorrhizal fungi.

In addition to the Internet search, 18 individuals who specialize in arid-land restoration were contacted by phone. These individuals were requested to provide information pertaining to current (1995-1999) restoration projects and research in the Mojave Desert and surrounding areas, with a particular interest in unpublished and/or difficult to find literature. Verbal information of restoration-related work was also recorded from each phone conversation. Managers generally reported use of traditional arid-land reclamation techniques and methods consisting primarily of transplanting and seeding operations. Native species were used in most current projects, although some introduced species were still being utilized in others. The reported success of these restoration projects was highly variable.

5.2 Threshold Levels

The impacts of military training include such things as: mechanical damage to plants, compaction of soils that restrict root growth and the establishment of new seedlings, loss of soil structure that inhibits infiltration of precipitation, loss of soil nutrients and organic matter that accelerate erosion and sandblasting of young plants, and loss of beneficial soil microorganisms that provide nutrients to plants and bind soil particles together (biotic crusts). Under severely disturbed conditions, mature plants capable of producing seed are lost and the soil seed bank becomes depleted. Valuable resources such as topsoil and nutrients may be lost. Soils under further degradation may become hydrophobic, with increased temperature and salinity that may inhibit germination and growth of new plants.

Figure 18 shows the key phases of habitat degradation that result under increasing disruption from military training. Phase I represents habitat in relatively undisturbed conditions with a full complement of plant species and undisturbed community structure and composition. As light disruption begins, there is usually a loss of plant vigor of sensitive species categorized as Phase II. Under moderate disruption levels (Phase III), there is a loss of sensitive species. During heavy disruption levels (Phase IV), there is a loss of not only the sensitive species, but also the resistant species. During very heavy disruption levels, even resistant species lose vigor until little or no seed or plants remain. Soil resources such as nutrients, organic matter, soil microorganisms, and even topsoil are lost by wind and water erosion.

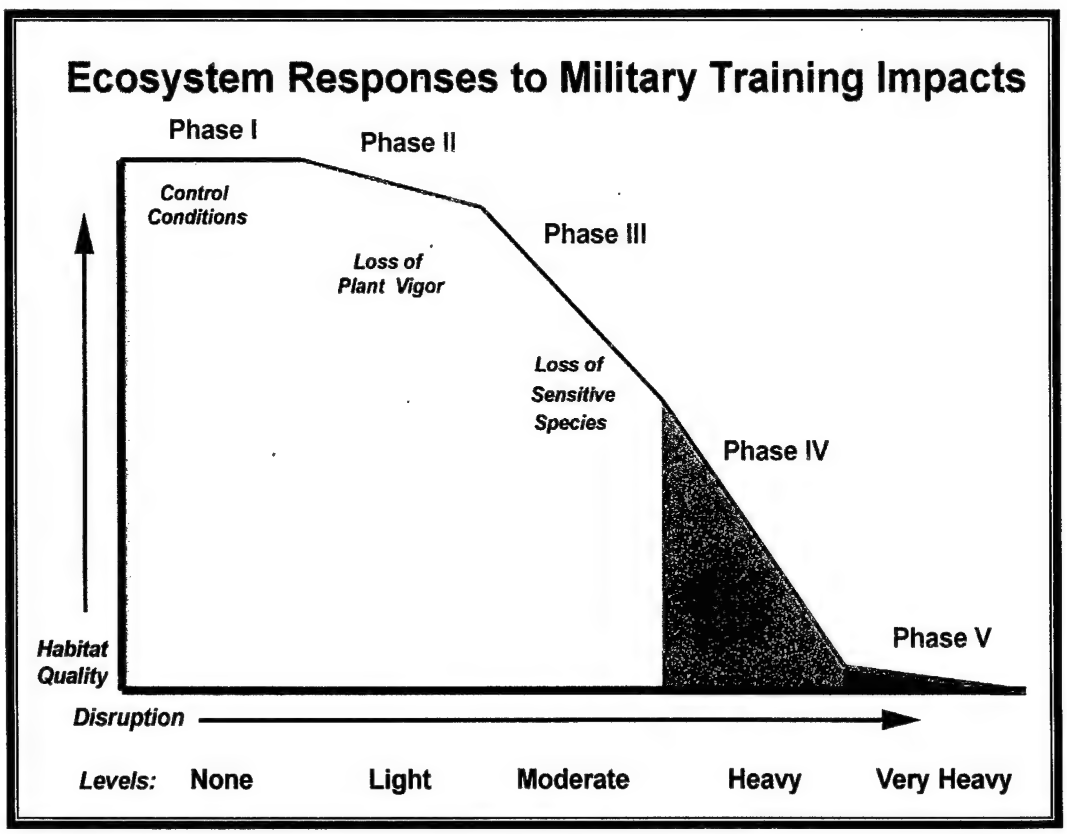


Figure 18. Key phases of habitat degradation from increasing military training impacts.

The few plants that do become established are severely challenged by increased evapotranspiration and damage from insects such as ants and small mammals. The lack of water in arid and semiarid military ranges is perhaps the most limiting factor in the growth and resiliency of vegetation to withstand training impacts (Wallace and others, 1980; Verma and Thames, 1978). In desert areas, the cost of recovery, risk of failure, and time needed for recovery increase dramatically and curvilinearly with the severity of impact (Figure 19).

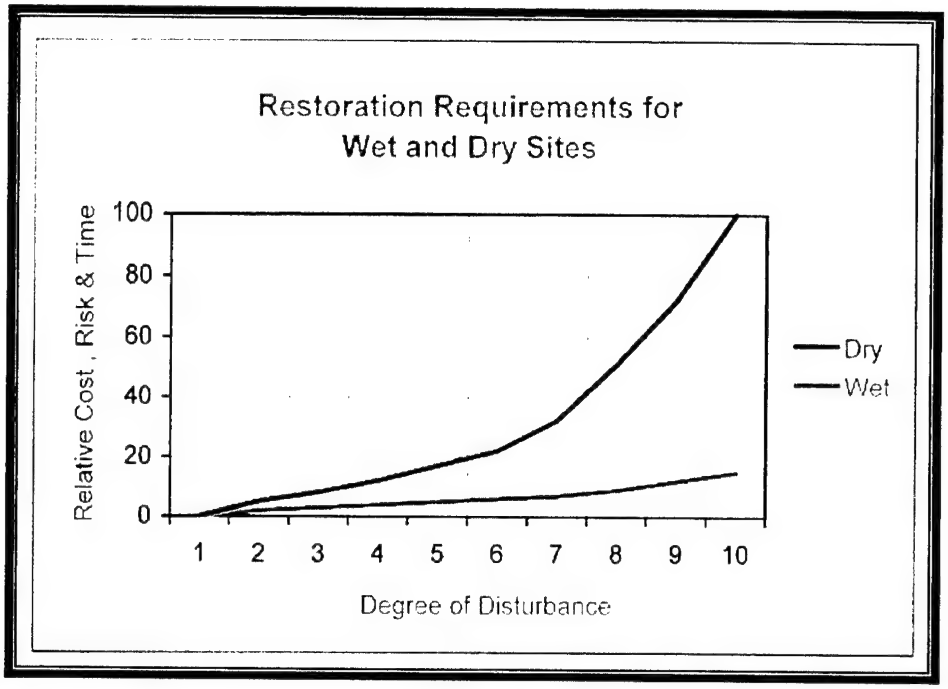


Figure 19. Costs, risks, and time required for recovery following disruption all increase more rapidly in dry environments than in moist environments.

In moist environments, costs and associated restoration requirements increase only slightly with increase in level of disruption because there are fewer limiting factors in moist environments and recovery is more dependant on the vegetative growth rate. In arid ranges, the impacts to vegetation become increasingly severe as training impacts increase in frequency and duration at rates that are disproportionate to early stages of disturbance. Even under natural conditions, severely disturbed sites in the Mojave Desert are projected to take up to 200 years to restore vegetation comparable to predisturbance conditions (Figure 20) (Angerer and others, 1994; Vasik, 1983; Webb and Wilshire, 1980). Lands that have been drastically disturbed in deserts create serious challenges to revegetation. Frequent and continued impacts require new restoration techniques to increase cost efficiency of mitigation efforts and to enhance natural plant establishment in synchrony with natural, often unpredictable climatic patterns.

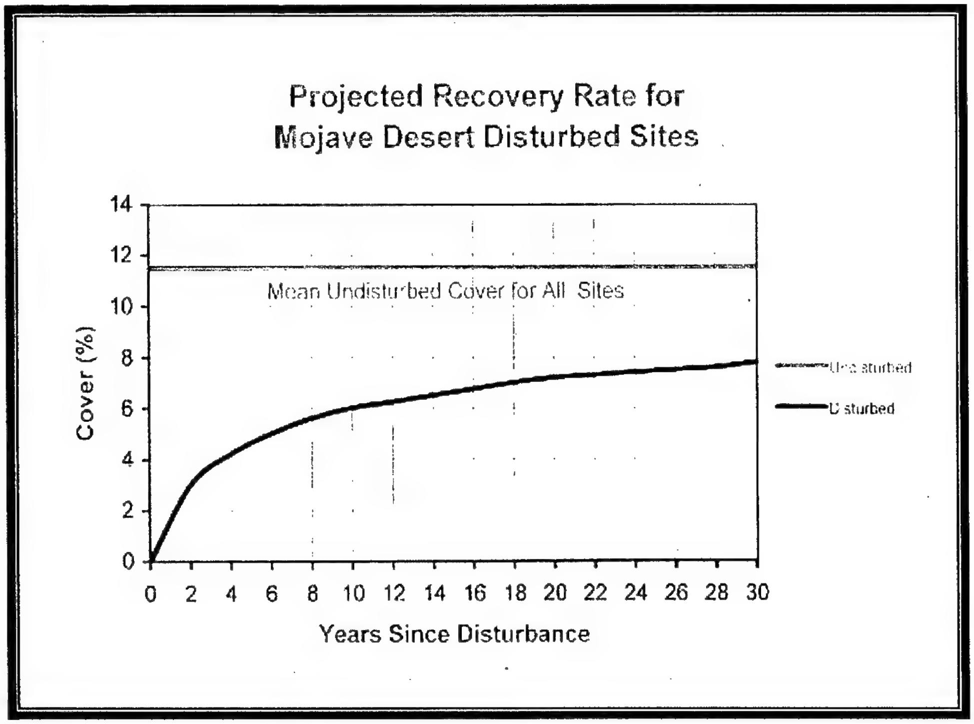


Figure 20. Projected recovery for disturbed vegetation may require hundreds of years to achieve predisturbance levels of vegetation cover in arid lands.

5.3 Reclamation Workshop

The workshop was planned as an initial activity for this project as a way to get input and support from recognized experts in arid land reclamation. Planning for the workshop was conducted by BN staff in concert with specialists contracted from other organizations. The Workshop Coordinator was Dr. Cy McKell, President of AES and former Dean of Science at Weber State University. Dr. McKell and Dr. Von Winkel, Senior Scientist, SAIC, served as moderators of the various sessions of the workshop. The time chosen for the workshop was soon after the project was initiated not only to gain the input of the technical community, but also to be at a time when participants were available before they initiated fall field activities and academic duties at universities. Fort Irwin, California, was the general location of reference for the workshop, but areas of similar climate, vegetation, soils, and type of use by DoD and DOE were considered in the planning, presentations, and discussions.

The main purpose of the workshop was to obtain the recognition, review, and input of technical and scientific specialists involved in remote sensing of land conditions and in arid land revegetation. By inviting recognized specialists in remote sensing and revegetation to present their work on topics of current interest, the project benefited by hearing up-to-date presentations and discussions of work that are highly relevant to the project. The workshop also provided an opportunity for review and comment on several project field activities planned for the fall/winter season of 1999 and 2000.

Invitations to attend the workshop were sent to more than 90 remote sensing/GIS and revegetation specialists in military units, government agencies, universities, and private industry. Previously, lists of attendees at workshops, conferences, and technical training sessions were screened by project staff to develop the mailing list for the workshop. The number of people invited to attend was intentionally kept modest to have the number of people attending the workshop at a workable size that would facilitate comments and discussions and involve a high proportion of the audience in a classroom setting. A high proportion of those invited accepted the invitation to attend; some sent regrets that they were involved in other meetings and did not have the date available. More than 55 specialists attended the workshop, giving it a balanced composition of experience and research in problems common to the arid and semi-arid environmental setting chosen for the workshop.

The workshop program was designed to obtain presentations of current work and to stimulate discussion and review of topic areas. The schedule of topics and names of presenters are shown in Appendix 8.2. Presenters were encouraged to highlight recent progress in techniques and materials, as well as areas of their disciplines where gaps in knowledge and more field testing is needed. Prior to the workshop, each person presenting a topic provided an abstract containing highlights of the topic covered. All abstracts were photocopied and provided to attendees as they registered for the workshop. After each group of presentations, 30 minutes were scheduled for questions and discussion, led by a moderator.

The workshop began with a brief welcome and introductions, followed by a discussion by Dr. Ostler of workshop objectives. Two presentations described some of the needs and problems in remote sensing analysis of vegetation/ land condition to provide a background for understanding how remote sensing and analysis were important to the whole problem of site analysis and revegetation. Subsequently, three topics on diagnostic tools and techniques, five topics on applications, and three topics on new diagnostic techniques were presented and discussed. At the end of the day, a poster session of eight poster boards were displayed to allow those in attendance to view the work and to have informal visiting time.

On the second workshop day, the focus was on arid land revegetation methods and materials. Five presentations outlined reclamation needs, followed by four topics on plant materials for reclamation. The afternoon session consisted of five presentations on reclamation techniques. The day concluded with a presentation of experimental designs for three field experiments planned for the fall/winter period and the environmental constraints of working on an active training site (Fort Irwin). The general consensus on the experimental design was that it contained too many factors and too many levels within factors, which would cause the experiments to be too large and costly. Suggestions were made to use past experience and research to omit or limit the number of factors/levels within factors. Several suggestions were offered on possible soil amendments, particularly those that enhanced soil microbial action and nutrient cycling. A general discussion was conducted at the end of the workshop to summarize reclamation tools.

Appendix 8.3 provides a summary of the workshop presentations and discussions.

5.4 Selection of Restoration Trials

The resiliency of a site to training exercises depends on the frequency and nature of the impacts, as well as the site potential for restoration. The site potential for restoration is determined by such things as plant species present, seed bank, soil moisture, soil texture, and available nutrients. At some sites, a shift in the plant community composition may also occur, with more sensitive species being replaced by plants more resistant to training impacts. Recovery may occur naturally and keep pace with the level of disturbance at some sites, depending on the nature and frequency of the disturbance, or it may require selected restoration techniques to recover from adverse training impacts before sustainable restoration is achieved.

Several revegetation techniques have been used by project personnel to accelerate the recovery process in desert environments. Combinations of innovative revegetation techniques developed at the NTS and other disturbed sites in the Mojave Desert will be applied to disturbed lands at Fort Irwin. Reclamation equipment to implement these treatments will be provided by the DOE. The primary questions to be answered are, At what degree of disturbance and vegetative condition is a site no longer capable of regenerating itself? and what are the costs, time, and techniques needed to return a site to a sustaining usable condition given various degrees of site degradation?

The proposed approach included the establishment of study plots representing three classes or degrees of disturbance ranging from moderate disturbance to very heavily disturbed sites (non-vegetated). Reclamation treatments and the number and size of plots were presented at the workshop. This experimental design was then refined using input from other reclamation experts during the reclamation workshop. The experimental design was then reviewed by a BN statistician to ensure that proper analyses could be conducted. The design consists of a set of treatments that is unique for each of the three levels of disturbance (moderate, heavy, and very heavy) that are being reclaimed. Thus, there are really three separate experiments that are being conducted and each will be analyzed separately.

Because soils play such an important role in the effectiveness of recovery treatments, it was decided that from three to five separate locations representing the major soil types at Fort Irwin were needed to adequately evaluate the impact of soils on recovery of desert vegetation. Soil samples taken from prospective locations showed that the soils were very sandy, which means they would hold very little moisture for plant use, and they contained very low levels of nutrients including negligible amounts of organic matter.

The other critical factor that was recognized during the workshop was the need for water for both new seedling establishment and for recovery of damaged plants. Irrigation would be applied to the three disturbance level plots, but the actual amounts and timing would vary with the particular objective for the disturbance level. For example, irrigation at moderate disturbance plots would consist of larger amounts of water applied at fewer periods to encourage movement of water deeper into the soil profile which stimulates established plants (McDonald and others, 1999). Supplemental water was particularly important for short-term experiments such as this that could not wait for natural rainfall. A third factor, seeding of native species adapted to site conditions, was identified and agreed upon as being sufficiently important that it should be tested

at all disturbance levels.

Other treatments were selected to address the specific needs of each disturbance level. For example, on the very heavy disturbance sites, compaction of the soil was very evident. These sites would require ripping to relieve that condition and enhance plant growth. Other treatments that will be tested in the very heavy sites include the addition of organic matter/nutrients to stimulate soil microorganisms and reestablish nutrient cycling, and surface stabilizers (straw and chemical) to control surface soil erosion until plants can become established. Treatments in the heavily disturbed sites included the addition of micro-nutrients and low levels of macro-nutrients to enhance seedling growth, as well as to stimulate existing plants on these sites. Ripping to relieve compaction and surface stabilization with straw was to be applied to all plots within this disturbance level. Treatments within the moderately disturbed sites included various levels of micro- and macro-nutrient additions. Irrigation application was designed to enhance growth and reproduction of established plants and not necessarily to establish new seedlings. Control treatments were also identified to determine what would happen with no active revegetation efforts.

Thirteen potential sites or areas varying in size from 1 to 4 hectares (100 m × 100 m to 200 m × 200 m) were identified with the aid of Fort Irwin staff and soils and vegetation data from Fort Irwin (Figure 21). Potential sites were placed in areas of typical use. Areas in the western and northern portions of Fort Irwin were excluded because of access restrictions. It was anticipated that some of these areas may not be available for our use because of military training needs or conflicts. Once these sites are approved for use, they will be placed on maps within the Fort Irwin GIS and identified as exclusion zones. Protection of these plots will be enhanced by marking the boundaries in the field with fence posts and cyber stakes. Even with these protection efforts, it is anticipated that some disturbance will occur. If this happens, those disturbed portions within plots will be excluded from future sampling or analysis.

Two additional sets of plots will be established at two sites within the very heavy disturbance level. They will differ from the other plots in that they will be intentionally disturbed to simulate continued impacts from military training exercises. Thus, the reclamation trials at Fort Irwin will evaluate vegetative recovery under three conditions: (1) protection from continuing impacts with only natural processes to aid recovery, (2) protection from continuing impacts with technologically assisted aid to recovery, and (3) technologically assisted aid to recovery, but with no protection from continued impacts. From this combination of treatments, major costs and time requirements can be determined for modeling and establishment of cost effectiveness per unit of time and degree of training impact.

Vegetation and site conditions will be documented in representative areas for each degree of disturbance. Ground data from the sites will be correlated with remote sensing data. Field data will be taken over the four-year period by the proposed image collection techniques previously described. The reclamation plots will be evaluated annually by techniques previously described. Findings will be evaluated and reported annually at SERDP symposia. At the conclusion of the four-year study, the continuation of plot monitoring and evaluation will be conducted by ITAM scientists and natural resource specialists from Fort Irwin.

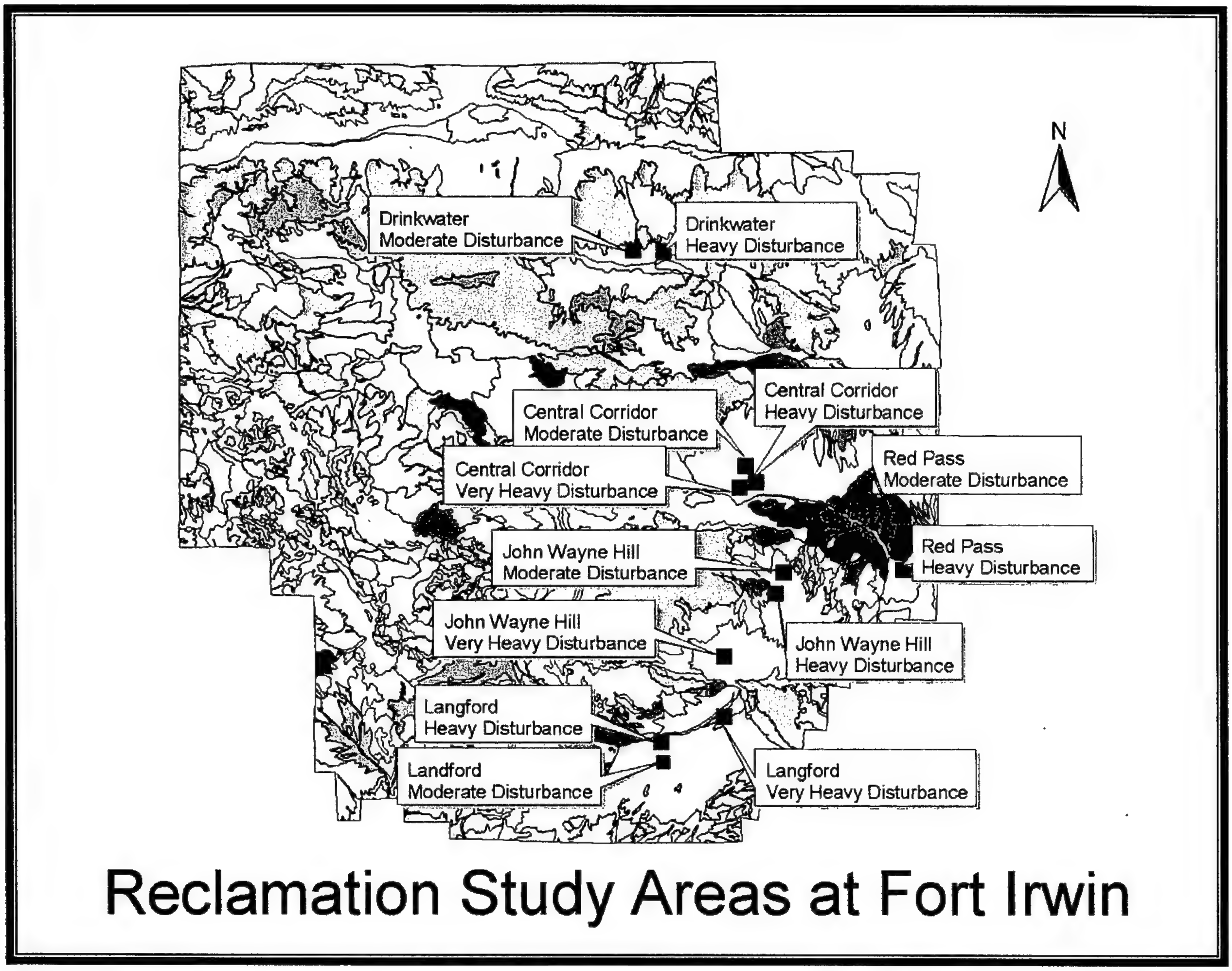


Figure 21. Location of 13 reclamation study areas (red boxes) at Fort Irwin. (Colored polygons indicate soil types.)

5.5 Acquisition of Reclamation Materials

Following the workshop and selection of the techniques that would be tested and after the reclamation study sites were approved, project scientists were able to actively pursue obtaining the materials needed for these experiments. Bechtel Nevada staff had previously identified and contacted reclamation suppliers who could provide seed of suitable species and other reclamation materials, but place final orders could not be placed for seed or materials until the final experimental design and approval of study locations were obtained. Initial subcontracts for irrigation equipment and other support were established once sites were approved and techniques finalized. Arrangements were made for the transfer of DOE reclamation equipment to Fort Irwin to be used during the December implementation period. Much of this task remains to be completed in the last quarter of 1999.

6.0 TECHNOLOGY TRANSFER

Coordination is anticipated and encouraged because project goals and objectives of this project are related to other DoD facility needs and other SERDP Mojave Desert projects. Project scientists have attempted to inform ITAM members, other DoD land and reclamation managers, and researchers of project efforts through invitations to the August workshop, through attendance and poster sessions at other workshops, and through other joint projects. From these efforts, Geotif and MRSID files were obtained from Fort Irwin (1:24,000 scale) and a correlation effort was initiated with recent aerial photography of Fort Irwin taken in January 1999 by BN's Remote Sensing Laboratory and satellite imagery processed by CSUDH. An article about the project was published in the July 19 issue of the *Federal Computer Week* newspaper (Johnston, 1999).

6.1 Pertinent DoD Models

During the first year of the study, Dr. Warren contacted modelers working with applicable models such as ATTACC, and models in LCTA and TMSES programs. Vegetation parameters that are used as input to these models were identified.

6.2 ITAM Meeting

Dr. Ostler attended the eighth annual ITAM workshop in St. Cloud, Minnesota, in late August. Several papers and posters were presented that have direct application to this project. Dr. Ostler met with several ITAM staff from the various facilities in the Southwest who would be potential users of techniques developed during this project. He also met with other researchers regarding possible interactions in the areas of carrying capacity and impact models, and soil and reclamation work being conducted at Fort Irwin.

6.3 Interactions with Other SERDP Projects

To date, four meetings have been held with principal investigators from SERDP projects CS-1098 and CS-1055 to discuss ways of collaborating on research and sharing data. Principal investigators from both projects attended a workshop on August 2-3, 1999, in Las Vegas sponsored by this project to share research ideas. Images were received from Dr. Paul Tueller (CS-1098) in August and analyzed to determine usefulness for their project. Dr. Tueller was also invited (together with personnel from CSUDH and Fort Irwin) to a SigmaScan Pro™ training session held in Las Vegas in March 1999. A meeting was also held on September 2, 1999, in Reno, Nevada, with Dr. Dave Mouat, Dr. Eric McDonald, and other Desert Research Institute scientists to discuss collaboration of research efforts. Dr. McDonald is currently doing soil moisture modeling under various reclamation strategies at Fort Irwin.

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8.0 APPENDICES

8.1 References from Data Gathering
8.2 New Technologies to Assess Vegetation Changes and to Reclaim Arid Lands Program
8.3 Summary of Workshop Presentations and Discussions

APPENDIX 8.1

LIST OF MOJAVE DESERT AND ARID LAND RECLAMATION PROJECTS AND RELATED INFORMATION

List of Mojave Desert and Arid Land Reclamation Projects and Related Information

Al-Awadhi, N., M.T. Balba and C. Kamizawa. 1996. Restoration and rehabilitation of the desert environment. Technical paper presented at the joint Kuwait-Japanese symposium, Amsterdam; New York: Elsevier.
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Website location: http://ser.org/Seattle/Soils.html

Allen, E.B., B.E. Heindl and J.P. Rieger. 1993. Trajectories of succession on restored roadsides in Southern California. 1993 SER Conference Presentation abstract: *Semi-arid and Arid Restoration*. Society for Ecological Restoration.
Methods described: seeding, mycorrhizae
Information provided: abstract
Website location: http://ser.org/irvine/semiarid.html

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Information source: Desert Lands Restoration Task Force
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Website location: http://www-rohan.sdsu.edu/dept/serg/desrestref.html

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Information source: Desert Lands Restoration Task Force
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Methods described: propagules, planning suggestions
Information provided: abstract
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Methods described: revegetation and soil analysis
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Website location : http://www.serg.sdsu.edu/SERG/curproj.html

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Methods described: Imprint seeding
Information provided: abstract
Website location: http://ser.org/irvine/desert.html

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Reference Information: SDMT, California Desert Managers Group Science and Data Management Team
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Methods described: seeding, transplants, fire, native species revegetation
Project location: Lassen Co., California
Information provided: abstract
Website location: http://endeavor.des.ucdavis.edu/cerpi/projectdescription.asp?ProjectPK=4173

Eagle Lake Field Office and P. Brink. 1999. GAGEJA native plant restoration study - mud flat watershed. California Ecological Restoration Projects Inventory (CERPI). U.C. Davis, California.
Methods described: seeding, native species revegetation
Project location: Lassen Co., California
Information provided: abstract
Website location: http://endeavor.des.ucdavis.edu/cerpi/projectdescription.asp?ProjectPK=4186

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Methods described: topsoil requirements, ripping, broadcast seeding and transplants
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Website location: http://endeavor.des.ucdavis.edu/cerpi/projectdescription.asp?ProjectPK=4762

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Methods described: mulching, imprinting, pitting and drilling
Project location: Imperial Co., California
Information provided: reference only
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Methods described: erosion control, decompaction and seeding
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Project location: Riverside Co., California
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Methods description: habitat restoration, topsoil stockpiling for mine reclamation.
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Methods description: vegetation transplanting
Species described: *Sphaeralcea ambigua*, *Atriplex canescens* and *Stipa speciosa*
Information provided: abstract
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Species description: *Atriplex polycarpa*, *Atriplex canescens* and *Larrea tridentata.*
Information provided: abstract
Website location: http://ser.org/irvine/semiarid.html

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Species description: *Larrea tridentata*, *Ambrosia dumosa* and *Coleogyne ramosissima*
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Methods description: waterbars, vertical mulch, native plant revegetation., scarifying disturbed areas, and desert tortoise habitat restoration.
Species description: *Larrea tridentata*, *Hymenoclea salsola*, *Ambrosia dumosa*, *Yucca brevifolia*, cholla, *Atriplex* species, and *Achnatherum hymenoides*
Information provided: abstract
Website location: http://endeavor.des.ucdavis.edu/cerpi/projectdescription.asp?ProjectPK=4461

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Website location: http://ser.org/irvine/island.html

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Methods description: soil amendments, mycorrhizae, mulches, and seedling propagation and planting
Species description: *Larrea tridentata*, *Ambrosia dumosa*, *Hilaria jamesii* and *Atriplex* species
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Methods description: perennial plantings, soil replacement, and annual seeding
Information provided: abstract
Website location: http://ser.org/Seattle/Indigenous.html

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Information provided: abstract
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Methods described: greenstripping, fire, herbicides and grazing
Information provided: abstract
Website location: http://ser.org/Seattle/Arid.html

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Project location: Tulare Co., California.
Methods description: Re-establishing microtopography
Information provided: abstract
Website location: http://endeavor.des.ucdavis.edu/cerpi/projectdescription.asp?ProjectPK=2003

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Project location: Riverside Co., California
Methods described: restoration of Desert Tortoise and Desert Bighorn habitat using 9 Colorado Desert native species.

Information provided: abstract
Website location: http://endeavor.des.ucdavis.edu/cerpi/projectdescription.asp?ProjectPK=4691

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Project location: Riverside Co., California
Methods described: transplanting *Coleogyne ramosissima* and *Yucca brevifolia*
Information provided: abstract
Website location: http://endeavor.des.ucdavis.edu/cerpi/projectdescription.asp?ProjectPK=4689

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Project location: Riverside Co., California
Information provided: reference only
Website location: http://endeavor.des.ucdavis.edu/cerpi/projectdescription.asp?ProjectPK=4686

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Project location: Riverside Co., California
Methods described: transplants from 6 native Mojave Desert species using four different soil amendments
Information provided: abstract
Website location: http://endeavor.des.ucdavis.edu/cerpi/projectdescription.asp?ProjectPK=4688

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Project location: Plumus Co., California
Methods described: soil fertility improvement, exotic species control and wildlife habitat restoration initiatives.
Information provided: abstract
Website location: http://endeavor.des.ucdavis.edu/cerpi/projectdescription.asp?ProjectPK=5016

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Project location: Riverside, California
Methods described: native species revegetation and erosion control
Information provided: abstract
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Website location: http://www.xmission.com:80/~rmrs/pubs/INTpubs/gtr315/315intro.html

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Information provided: reference only
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Reference information: commonly used restoration plant species
Information provided: full document
Website location: http://www.serg.sdsu.edu/SERG/plants.html

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Information provided: reference
Website location: http://www.serg.sdsu.edu/SERG/serg.html

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Methods described: site preparation, irrigation, soil pitting, ripping and broadcast seeding
Information provided: abstract
Website location: http://www.serg.sdsu.edu/SERG/irwinover.html

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Methods described: vertical mulch, pitting and transplanting
Information provided: abstract
Website location: http://www.serg.sdsu.edu/SERG/Demoplot.html

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Project description: seed collection for arid-land restoration
Information provided: full document.
Website location: http://www.serg.sdsu.edu/SERG/seedcoll.html

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Methods described: transplants, Driwater and seeding
Information provided: full document
Website location: http://www.serg.sdsu.edu/SERG/fidamlan.html

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Methods described: use of windbreaks to reduce erosion potential
Information provided: full document
Website location: http://www.serg.sdsu.edu/SERG/wndbrk.html

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Methods described: GIS, seed collection, ripping, pitting and soil amendments
Information provided: full document
Website location: http://www.serg.sdsu.edu/SERG/gisfyp.html

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Methods described: windbreaks, pitting and seeding
Species described: *Ambrosia dumosa*, *Larrea tridentata* and *Hymenoclea salsola*
Information provided: full document
Website location: http://www.serg.sdsu.edu/SERG/fipcrest.html

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Methods described: transplanting and irrigation
Species described: *Larrea tridentata, Ambrosia dumosa, Ephedra nevadensis* and *Hymenoclea salsola*
Information provided: abstract
Website location: http://www.serg.sdsu.edu/SERG/fierosion.html

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Methods described: revegetation and dust control
Species described: *Atriplex* species, *Larrea tridentata, Prosopis glandulosa* and *Chrysothamnus nauseosus*
Information provided: abstract
Website location: http://www.serg.sdsu.edu/SERG/antval.html

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Methods described: transplants, irrigation and Driwater
Information provided: abstract
Website location: http://www.serg.sdsu.edu/SERG/mmea.html

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Methods described: habitat assessment
Information provided: abstract

Website location: http://www.serg.sdsu.edu/SERG/ocowells.html

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Methods described: seeding, mulch, ripping/imprinting and VAM inoculation
Information provided: abstract
Website location: http://www.serg.sdsu.edu/SERG/pendmyco.html

SERG. 1999. Point Loma. SERG (Soil Ecology and Restoration Group) webpage, San Diego State University.
Project description: description of 3 associated arid restoration projects
Information provided: abstract
Website location: http://www.serg.sdsu.edu/SERG/point_loma.html

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Methods described: transplants and mulch treatments
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SERG. 1998. Revegetation project at marine corps air ground combat center at 29 Palms, California. SERG (Soil Ecology and Restoration Group) webpage, San Diego State University.
Methods described: irrigation, seeding, transplanting
Information provided: abstract
Website location: http://www-rohan.sdsu.edu/dept/serg/29palms.html

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Methods described: site preparation, soil manipulation, irrigation and plant protection
Information provided: abstract
Website location: http://www.serg.sdsu.edu/SERG/VSTOL_Project.html

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Methods described: transplanting, seeding, imprinting
Species described: *Atriplex canescens*, *Ambrosia dumosa* and *Encelia farinosa*
Information provided: full document
Website location: http://www.serg.sdsu.edu/SERG/29tanktrail.html

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Methods described: shrub transplanting
Species described: *Larrea tridentata* and *Yucca brevifolia*
Information provided: abstract
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Project description: Impacts of invasive species on arid-land restoration
Species described: *Artemisia californica*
Methods described: seeding, soil amendments
Information provided: abstract
Website location: http://www.serg.sdsu.edu/SERG/smbrabs.html

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Smith, L., P. Brink and G. Sharp. 1999. Ivanpah Dry Lake exclosure. California Ecological Restoration Projects Inventory (CERPI). U.C. Davis, California.
Project location: San Bernardino Co., California
Methods description: Fencing used to prevent land degradation
Information provided: abstract
Website location: http://endeavor.des.ucdavis.edu/cerpi/projectdescription.asp?ProjectPK=4638

Sorensen, N., D.A. Bainbridge and R.A. Virginia. 1993. Improving shrub establishment in arid-land revegetation: site preparation, microclimatic modification and nutrient addition. 1993 SER Conference Presentation abstract: *Desert Restoration*. Society for Ecological Restoration.
Methods described: seeding, seedling protection with tube treeshelters, irrigation with vertical pipes and ripping of compacted soil
Species description: *Ambrosia dumosa*
Information provided: abstract
Website location: http://ser.org/irvine/desert.html

Sprague, D. and M. Blane. 1999. Big Rock Creek. California Ecological Restoration Projects Inventory (CERPI). U.C. Davis, California.
Methods described: imprinting, transplanting and ripping
Information provided: reference only
Website location: http://endeavor.des.ucdavis.edu/cerpi/projectdescription.asp?ProjectPK=1045

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Project location: Riverside Co., California

Methods description: weed control and irrigation
Information provided: abstract
Website location: http://endeavor.des.ucdavis.edu/cerpi/projectdescription.asp?ProjectPK=1043

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Project location: Orange Co., California
Information provided: reference only
Website location: http://endeavor.des.ucdavis.edu/cerpi/projectdescription.asp?ProjectPK=4002

Sprague, D. and M. Blane. 1999. San Bernardino plant, phase A-1 & B-1 revegetation project. California Ecological Restoration Projects Inventory (CERPI). U.C. Davis, California.
Project location: San Bernardino Co., California
Methods described: habitat improvements and topsoil storage
Information provided: abstract
Website location: http://endeavor.des.ucdavis.edu/cerpi/projectdescription.asp?ProjectPK=1038

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Methods described: soil organic nitrogen amendment and fertile islands
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Methods described: revegetation, fencing, mulch and mycorrhizae inoculation
Species described: *Prosopis glandulosa*
Information provided: abstract
Website location: http://ser.org/Seattle/Mining.html

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Website location: http://wiscinfo.doit.wisc.edu/arboretum/rmn/homepage.html

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Wash, D., P. Brink and K. Wash. 1997. Kiavah & Owens Peak Wilderness Restoration. California Ecological Restoration Projects Inventory (CERPI). U.C. Davis, California.
Project location: Kern Co., California
Methods description: ripping, waterbars, vertical mulch and scarifying soil surface to restore hiking and ATV trails
Information provided: abstract
Website location: http://endeavor.des.ucdavis.edu/cerpi/projectdescription.asp?ProjectPK=4455

Wash, D., P. Brink and G. Williams. 1995. Trona Pinnacles National Natural Landmark Project. California Ecological Restoration Projects Inventory (CERPI). U.C. Davis, California.
Project location: Kern Co., California
Methods description: soil decompaction, surface restoration, scarifying, application of Permeon-synthetic desert varnish
Information provided: abstract
Website location: http://endeavor.des.ucdavis.edu/cerpi/projectdescription.asp?ProjectPK=4456

Watershed Projects Inventory. 1999. Watershed inventory project List. Watershed Projects Inventory (WPI) webpage. U.C. Davis, California.
Website description: list of many current restoration projects
Information provided: abstract
Website location: http://endeavor.des.ucdavis.edu/wpi/projectlist.asp

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Website description: riparian ecology and restoration, and watershed development
Information provided: abstract
Website location: http://endeavor.des.ucdavis.edu/wpi/habitatquery.asp?ppk=000015

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Project location: Yuba Co., California
Methods described: Lime and organic amendments
Information provided: abstract
Website location: http://endeavor.des.ucdavis.edu/cerpi/projectdescription.asp?ProjectPK=1089

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Methods described: transplanted shrub establishment following treatment, species selection, irrigation and plant adaptation
Information source: Reclamation Feasibility Studies at Yucca Mountain, Nevada: 1992-1995, Environmental Science Department, Yucca Mountain Project, Las Vegas, Nevada
Information provided: reference only

Telephone Contact List

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Michael Eichellenger, Viceroy Gold Corporation, (702) 252-8040
Rick Gatewood, Fort Bliss, (915) 568-0977
Jennifer Haley, Lake Mead National Recreation Area (NPS), (702) 293-8951
Derek Hall, Bechtel Nevada, (702) 295-0364
Art Hazebrook, Fort Hunter, (831) 386-2305
Valerie Merrill, US Army Yuma proving grounds, (520) 328-2244
Bruce Munda, NRCS plant materials center, (520) 670-6491
Alice Newton, Lake Mead National Recreation Area (NPS), (702) 293-8977
Heidy Reiser, Holloman Air Force Base, (505) 475-3931
Jane Rodgers, Joshua Tree National Park, (760) 367-5564
Anna Shrank, Joshua Tree National Park, (760) 367-5565
Ruth Sparks, Fort Irwin, (760) 380-5903
Chris Stubbs, Mojave National Preserve, (760) 255-8815
Tom Zink, San Diego State University, (619) 594-5697

APPENDIX 8.2

SERDP Workshop Program
August 2-3, 1999
Las Vegas, Nevada

NEW TECHNOLOGIES TO ASSESS VEGETATION CHANGES AND TO RECLAIM ARID LANDS

SERDP Workshop
New Technologies to Assess Vegetation Changes and to Reclaim Arid Lands
Program

Monday, August 2, 1999 ***Morning Session***

7:30 Registration and check in

WELCOME and OBJECTIVES – Cy McKell (moderator)

8:00 Welcome to Las Vegas and DOE Facilities

Cy McKell, AES
Rick Betteridge, DOE/NV

8:15 Strategic Environmental Research Development Programs

SERDP Representative

8:30 Goals and Objectives of the Workshop

Kent Ostler, BN

NEEDS and PROBLEMS – Cy McKell (moderator)

8:45 "Training needs and military impacts at Fort Irwin"

Ruth Sparks, CHARIS/Fort Irwin

9:05 "Determining land condition and trends at military training areas"

Steve Warren, CSU

9:30 Refreshment Break

DIAGNOSTIC TOOLS and TECHNIQUES – Von Winkel (moderator)

9:45 "The use of high-resolution aerial photography in the arid areas, its uses and limitations"

Paul Tueller, UNR

10:10 "Using multispectral imagery for environmental site characterization"

Mike Howard, BN-RSL

10:30 "The use of low resolution satellite imagery in arid areas: uses and limitations"

Alfredo Huete, OALS/UA

APPLICATIONS – Cy McKell (moderator)

11:00 "Mojave Desert Ecosystem Program"

Clarence Everly, Fort Irwin

11:30 "GAP Analysis in the Mojave Desert"

Katherine Thomas, BRD

12:00 BOX LUNCH

APPLICATIONS CONTINUED – Von Winkel (moderator) ***Afternoon Session***

1:00 "GIS and image processing to identify disruption levels"

Rod Hay, CSUDH

1:30 "Vegetation surveys and mapping on the Nellis Air Force Range"

Dave Anderson, BN

2:00 "Analysis and assessment of military and non-military impacts on biodiversity"

Mary Cablk, DRI

2:30 Refreshment Break

NEW DIAGNOSTIC TECHNIQUES – Cy McKell (moderator)

2:45 "Detecting change in arid vegetation cover using hyperspectral data"

Tim Minor, DRI

3:15 "High-resolution image collection and processing techniques"

Dennis Hansen, BN

3:45 "Laser induced fluoroscence imaging and spectroscopy to detect vegetation change"

Gene Capelle, BN-STL

DIAGNOSTIC TOOLS SUMMARIZATION – Cy McKell (moderator)

4:15 Discussion session and application questions
(Identify action items, potential cooperation, modifications, and concerns)

5:00 – 6:30 POSTER SESSION/TECHNICAL ADVISORY COMMITTEE MTG.

Tuesday, August 3, 1999 ***Morning Session***

RECLAMATION NEEDS and PROBLEMS – Von Winkel (moderator)

8:00 "The challenges of arid-land reclamation"
Martin Karpiscak, OALS, UA

8:30 "Aeolian influences on soils in the Mojave Desert"
Eric McDonald, DRI

9:00 "Military impacts at US Army Yuma Proving Grounds and reclamation needs"
Valerie Morrill, YPG

9:20 "Military training impacts at Fort Bliss and reclamation needs"
Brett Russell, Ft. Bliss

9:40 "Military training impacts at Fort Irwin and reclamation needs"
Ruth Sparks, CHARIS/Fort Irwin

10:00 Refreshment Break

PLANT MATERIALS FOR RECLAMATION – Cy McKell (moderator)

10:15 "Meeting the germplasm needs of the future"
Kevin Jensen, USDA-ARS Logan

10:40 "Plant materials for arid lands"
James Young, USDA-ARS Reno

11:10 "Seed collection in arid lands"
Bill Agnew, Granite Seeds, Lehi, UT

11:35 "Nursery stock for arid lands"
Anna Schrenk, Joshua Tree, native plant nursery

12:00 BOX LUNCH

RECLAMATION TECHNIQUES – Von Winkel (moderator) **Afternoon Session**

1:00 "Habitat reclamation atYucca Mountain, Nevada"

Kevin Blomquist, SAIC/YMP

1:20 "Revegetation at Fort Irwin"

Scott Delman, SDSU

1:40 "Evaluation of chemical soil stabilizers for use during soil remediation projects"

David Anderson, BN

2:00 "Supplemental water to enhance germination and establishment"

Derek Hall, BN

2:20 "Establishing sustainable native plant growth on drastically disturbed soils in harsh environments"

Peter McCrae, Quattro Environmental
Ed Kleiner, Comstock Seed

3:00 Refreshment Break

EXPERIMENTAL DESIGN – Cy McKell (moderator)

3:15 "Environmental conditions and constraints at Fort Irwin"

Kent Ostler, BN

3:30 "Identification of plant stress threshold levels subjected to controlled disruption"

Dennis Hansen, BN

3:45 "Experimental design of proposed revegetation study areas at Fort Irwin"

Dave Anderson, BN

RECLAMATION TOOLS SUMMARIZATION – Cy McKell (moderator)

4:30 Discussion session and application questions
(identify action items, potential cooperation, modifications, and concerns)

APPENDIX 8.3

SUMMARY OF WORKSHOP:
NEW TECHNOLOGIES TO ASSESS VEGETATION CHANGES AND TO RECLAIM ARID LANDS

SUMMARY OF WORKSHOP: "NEW TECHNOLOGIES TO ASSESS VEGETATION CHANGES AND TO RECLAIM ARID LANDS"

INTRODUCTION

The project, "Diagnostic Tools and Reclamation Technologies for Mitigating Impacts of Department of Defense (DoD)/Department of Energy (DOE) Activities in Arid Areas", is part of the Conservation Thrust Area of the Strategic Environmental Research and Development Program (SERDP). The purpose of the SERDP is to address DoD and DOE environmental concerns, share data collection and analysis capabilities, identify and share research technology, and identify private sector technologies useful to the DoD and DOE. The studies proposed for this project address environmental concerns associated with land impacts that threaten future training on military lands in arid and semi-arid areas. This project is a cooperative effort between the DoD, DOE, and selected university scientists and will be conducted primarily at the National Training Center located at Fort Irwin. The project's technical objectives are to develop and apply diagnostic techniques to identify disruption thresholds; develop, apply, and evaluate restoration techniques; and transfer these technologies to other sites and climatic areas.

On August 2-3, 1999, a workshop was held in Las Vegas, Nevada in support of the project. The objectives of the workshop were to ensure that potential techniques for assessing vegetative change and reclaiming disturbed lands were not overlooked, and to refine the methodologies and treatments currently proposed for this project. Presentations were given that described the ecological impacts from military training at Fort Irwin and the challenges associated with reclaiming disturbed lands in the arid southwest. Remote-sensing techniques that have the potential to assess vegetation change were presented. These techniques use a variety of imagery sources and parameters to quantify changes in vegetation or land use. Presentations were given that discussed the effectiveness of reclamation techniques such as irrigation, mulching, soil inoculation, direct seeding, and transplanting. Controlled disruption treatments and reclamation treatments also were presented for review. Throughout the workshop participants were encouraged to discuss these techniques as they applied to the goals of the project.

This report summarizes the issues and comments that were raised during the workshop. The presentations are summarized according to the four general topics that were addressed during the workshop: 1) Problem Statement, Needs, and Objectives; 2) Remote Sensing and Diagnostic Tools to Detect Vegetation Change; 3) Reclamation; and 4) Experimental Design and Study Implementation Logistics. For each topic, a brief narrative summarizing the presentations is included, followed by a discussion of the issues and comments that were raised.

SUMMARY TOPICS

PROBLEM STATEMENT, NEEDS, AND OBJECTIVES

Continued military training is threatened by ecological impacts to arid and semi-arid areas. Direct impacts (soil compaction, soil structure breakdown, and vegetative mortality) are caused by military vehicle traffic during training exercises. These direct impacts lead to other indirect effects that may result in an unrealistic military training environment, an increase in vehicle maintenance costs, and situations that are dangerous to personnel (i.e. reduced visibility from high dust levels or respiratory problems). Additionally, high dust levels caused by training on degraded land may affect nearby population centers and parks that are outside military controlled lands. Current training levels are not sustainable because environmental impacts will result in a reduction of current training levels or a suspension of training altogether. Thus, cost-effective techniques are required to identify disruption thresholds and to return disturbed areas to a form that enables continued military training.

Models that are used for assessing the level (Maneuver Impact Miles) or consequence (soil erosion, wind erosion) of training impacts were presented. Possible data parameters needed to drive future models were also discussed.

Steve Warren (Colorado State University) presented models that are used or being developed, such as the Army Training and Testing Area Carrying Capacity (ATTACC) and the Wind Erosion Prediction System (WEPS), to determine impact levels and whether or not these impacts are sustainable. He also addressed data needs that may be required for future models. These data needs included:

- horizontal and vertical structure of the canopy for tactical concealment, training realism, and affects on wildlife
- Botanical composition
- Living and dead plant biomass
- Plant height, diameter, and density
- Surface features of the land
- Roughness factors (Manning's N)
- Biological soil crusts
- Desert pavements

Dennis Hansen (Bechtel, Nevada) stated the importance of knowing the parameters needed in the future so that current research designs accommodate collection of appropriate data. Presentations by Paul Tueller (University of Nevada, Reno) and D. Hansen discussed remote sensing techniques used to generate data for parameters such as plant structure, density, and cover. However, during the workshop, no models were specifically identified for integration into the research at Fort Irwin.

Based on Ruth Sparks' (Charis Corp., Fort Irwin) presentation, some areas at Fort Irwin are very heavily disturbed (ex. parking areas, staging areas, and main roads). Participants agreed that reclamation of these areas would not be prudent in most situations. However, reclamation of very heavily disturbed areas was proposed for study during this project and R. Sparks noted that in some instances, reclamation of these areas might be necessary. Martin Karpiscak (University of Arizona) brought up two related issues. First, a process is needed to identify whether or not a heavily disturbed area will be reclaimed. Second a plan is needed for managing heavily disturbed areas that won't be reclaimed. It was suggested that disturbed areas be categorized by the landscape or vegetation type in which they occur. Based on this categorization, disturbance areas within abundant landscapes or vegetation types would be sacrificed first. Valerie Morrill (Yuma Proving Grounds) proposed hardening heavily disturbed areas with gravel, a practice she has used successfully in the past. Periodic chemical stabilization was also suggested as a management technique for heavily disturbed areas that would not be reclaimed.

REMOTE SENSING AND DIAGNOSTIC TOOLS TO DETECT VEGETATION CHANGE

High-resolution aerial photography, multi-spectral imagery, and Laser Induced Fluorescence Imaging were presented as techniques that could be used to detect vegetation change or stress. Techniques using aerial photography focus on measuring vegetative characteristics such as plant density and canopy cover. High-resolution photography also allows identification of individual plant species. Analyses of several parameters (ex. thermal reflectance, light reflectance, and textural attributes) taken from multispectral imagery were compared to field data (disturbance area and plant cover). Comparisons between the parameters and field data were made to determine if reliable relationships existed. Different types and resolutions of imagery were used for these analyses such as AVHRR, LANDSAT, and SPOT. Different spectral sampling intensities were also used. For example, some imagery techniques sample less than 10 bandwidths in the spectrum, while hyperspectral imaging may sample more than 120 bandwidths. Finally, a technique called Laser Induced Fluorescence Imaging was presented. This technique used a laser to detect different nitrogen levels from the fluorescence levels exhibited by a plant.

No single technique addressed all the questions regarding vegetation change or stress efficiently. Changes in vegetation can be documented easily with high-resolution photography; however, the amount of time required and thus the cost to photograph large areas may become prohibitive. As the resolution of the photography or imaging technique decreases, larger areas can be photographed more efficiently. However, the ability to monitor vegetation change decreases at these lower resolutions. Finally, many of these techniques, such as hyperspectral imaging, produce large amounts of information that is labor intensive and time consuming to analyze.

P. Tueller, noted that defining the components of the spectral signature from a mixed pixel (i.e., a pixel containing more that one component such as plants, litter, and bare ground) was difficult, especially when these signatures vary both spatially and temporally. Tim Minor (Desert Research Institute) presented a method to account for mixed pixels. This method used

endmembers to define spectral signatures of specific soil types and plant species for use in comparing remotely sensed vegetation cover with field collected vegetative cover. This method adjusted for mixed pixels and partially addressed the issue of spatial variability since the endmembers were based on the mean of several samples.

Chris Lee (California State University) discussed the process of normalizing images from different years to ensure that the same information was derived from each year. He normalized the images by locating areas that were consistent in terms of bright and dark targets from year to year. He then regressed the images from one of the years (the base image) to the images of the remaining years.

Soils have a large effect on the interpretation of remote sensing imagery. C. Lee showed that light and dark soil showed disruption differently. Dave Anderson (Bechtel, Nevada) found that soil color influenced multispectral imaging results more than existing vegetation. T. Minor found that soil endmembers were the most important factor for correlating the vegetation endmember and the vegetation data collected on the ground.

RECLAMATION

The reclamation section of the workshop focused on the challenges of arid-land reclamation, and the selection of reclamation techniques, and plant materials. One problem that was identified was the need for criteria for deciding which areas could be reclaimed while staying within the constraints of a budget. Additional problems included water limitations, physical and chemical problems of arid soils, and disruption or elimination of the soil biota. Methods that were presented for mitigating these problems included water harvesting, irrigation, and soil amendments such as straw mulch and polyacrylamide gel. Methods for inoculating soil with mycorrhizae and other materials designed to re-establish the nutrient cycling patterns were also presented. Presentations on plant materials included discussions on the use of locally collected seed versus native, non-local seed, or seed from introduced species. Plant establishment results from using transplants and direct seeding were presented. The importance of preplanning seeding efforts based on the vegetation of the disturbed area prior to reclamation was also discussed.

Based on presentations by M. Karpiscak and Eric McDonald (Desert Research Institute) the ability of soil to hold water and allow infiltration of water, greatly influences the water availability of plants. E. McDonald talked about how different soil types affect water availability and the importance of assessing disruption or degradation effects at the soils level. He discussed two tools (time domain reflectrometry and electromagnetic soil conductivity) he was using to determine how revegetation treatments affect soil water.

M. Karpiscak, E. McDonald, and Scott Delman (San Diego State University), discussed the use of macrocatchments as a technique to harvest water to increase plant survival. E. McDonald also presented results from modeling the effects of macrocatchment features on soil water. These results indicated that macrocatchments increased soil water in the plant growing area. Soil

sealants and water repellants were also mentioned as methods that could be used to further increase water runoff from catchment areas. D. Anderson mentioned that these methods were used during a wet year at the Nevada Test Site with little success.

Macrocatchments were not proposed as treatments in the reclamation studies at Fort Irwin, however, many workshop participants thought this method was viable, especially if complimented with the use of an effective soil sealant.

The use of locally collected seed, native non-local seed, or seed from introduced species for reclamation was an ongoing topic of discussion. Based on the objective of the work at Fort Irwin, it was proposed that native non-local seed be used. However, seed availability is often limited. Thus, on-site seed collection may be required. Bill Agnew (Granite Seed Company) stated that before a determination was made of the species that required on-site collection, an inventory of the species at the site was needed and an evaluation of what species were commercially available.

Kevin Jensen (Agricultural Research Service) spoke about genetically altering locally collected genotypes to enhance favorable characteristics such as drought resistance, persistence under disturbance, defoliation, and tillering. Developing these characteristics for key species in the desert southwest may be a possibility.

Irrigation was proposed as a method to generate consistent reclamation success. Factors that negate the effectiveness of irrigation were presented and include water quality and the properties of the soil where reclamation is being implemented. Older soils with large amounts of silt and clay at or near the ground surface have the potential to reduce infiltration, particularly when the soil is severely disturbed. Water should be tested for salts or toxic levels of nutrients. Amendments or cultural treatments should be considered to alleviate the "moon dust" property indicative of soil with high silt/clay content.

EXPERIMENTAL DESIGN AND STUDY IMPLEMENTATION LOGISTICS

The purposes of the design and logistics portion of the workshop were to 1) inform workshop participants about the environmental conditions and constraints of working at Fort Irwin, 2) discuss treatments to determine threshold disruption levels, and 3) present proposed revegetation treatments.

Several environmental conditions and constraints of working at Fort Irwin were noted. These included:

- variable conditions and gradients (different training levels, different soils, different vegetation associations, and changes in precipitation)
- limited availability of plant materials
- exotic species
- relatively short project duration

- emphasis on large scale techniques
- restricted access
- large distances between sites
- limited support facilities down range
- limited protection of study areas from military training exercises
- the need to demobilize all equipment between reclamation efforts.

Threshold disruption levels were defined as those levels at which certain characteristics or components of the vegetation were lost. The conceptual disruption levels that were presented from least disruption to greatest were: 1) loss of plant vigor, 2) loss of plants sensitive to disturbance, 3) loss of plants resistant to disturbance, and 4) loss of all perennial plant cover. Controlled disruption within undisturbed study areas was proposed to study plant stress threshold levels. The parameters that were presented to measure disruption levels were plant mortality, cover, and vigor. These investigations were designed to answer questions regarding the sustainability of military training at varying disruption levels. Peter McRae (Quattro Environmental) stated another threshold to consider was the point at which disruption in one area leads to accelerated loss of vegetative cover in adjacent undisturbed areas.

Proposed reclamation treatments included seeding, fertilizer, irrigation, mulching, fencing, and application of polyacrylamide gel. Different combinations of these techniques were proposed for evaluation in five soil types and three levels of disturbance (very heavy, heavy, and moderate). Workshop participants discussed the objective (restoration, reconstruction, revegetation) of the reclamation studies at Fort Irwin. Reconstruction (reclaiming with native species that are not comprised of local genotypes) was considered by participants to be the appropriate level of reclamation for this project. R. Sparks noted that the military training mission was different than the mission of conservation organizations such as the National Park Service, which strive for restoration.

Air quality was also discussed. It was agreed that air quality would decrease if nothing was done to control wind erosion and dust. As the land becomes increasingly degraded, air quality may prohibit continued military training. Because air quality is a compliance issue, it may become the military's motivation for reclaiming these areas.

Workshop participants expressed concerns regarding the experimental design.

- Too many factors fit into one study to be able to implement logistically and interpret statistically.
- Too many levels of a single factor (irrigation, fertilizer, etc.) in the design to be able to randomize. K. Jensen (Agriculture Research Service) noted that each nutrient (N, P, K, and all micronutrients) should be considered as a level and randomized accordingly.
- Participants suggested using past experience/research to omit and/or limit levels of factors.

It was agreed that the current set of treatment factors could not be statistically designed as a complete factorial. K. Jensen suggested the use of an incomplete block design or Analysis of Variance without replication to decrease the number of potential treatment plots.

Plant mortality and reduction in plant cover/vigor were identified as parameters for modeling impacts from controlled disruption by military vehicles. D. Hansen proposed the evaluation of several parameters prior to controlled disruption to assess prestress conditions. It was suggested that precipitation be included for measurement since this parameter has a direct influence on water availability that in turn affects plant stress.

S. Warren suggested that when measuring effects of different disruption levels, soil parameters should be measured, especially if air quality is an issue. Since vegetative cover is low in the Mojave Desert, rock cover and biotic crusts are often important soil characteristics that control dust. Rock cover (gravels and larger), infiltration, and compaction were listed as parameters for consideration.

Jane Rogers (Joshua Tree National Park) expressed concern regarding the quantification of vegetation damage resulting from a certain number of passes by military vehicles. This information may be misconstrued to mean that no damage occurs by running over vegetation, when in fact, damage has occurred even though the plants weren't killed.

C. Lee's presentation raised additional issues regarding the proposed controlled disruption study. In his opinion there were no longer any undisturbed areas on Fort Irwin to calibrate disturbance/disruption levels against. He also thought there was a lack of data from Fort Irwin on past use and an existing inability to derive these data for ongoing activities. The implementation of controlled disruption studies is dependent on the availability of undisturbed sites to ensure that existing vegetation has not been stressed from prior human disturbance.

The relationship between ongoing use levels and the resulting disturbance needs to be quantified. This relationship is required to model the degradation that occurs from different training scenarios and will help assess sustainable use levels.

Several comments relating to soil amendments were noted:

- It was suggested that fertilizers be tested in a greenhouse to decrease the number of treatments on the reclamation plots. It was noted that this idea would be considered; however, if a greenhouse was used, it would be difficult to test the disturbance factor.
- It was suggested that before fertilizer levels are defined, the soil should be tested to determine fertilizer needs.
- P. McRae suggested building soils up by using soil inoculants. It was also recommended that organic materials be used as fertilizer, rather than inorganic NPK, so that existing microorganisms are not eliminated. D. Hansen commented that the proposed fertilizer treatments included materials such as humates that are beneficial for soil biota.
- It was proposed that a 20:80 mix of topsoil:pulverized sand materials be considered as an alternative to fertilizer and soil inoculation. While this may be a possibility, the

availability of borrow material will be limited at most sites.

- It was noted that for reclamation trials at Yucca Mountain, polyacrylamide gel (PAM) crystals increased seedling densities, but this did not translate into increased plant survival after two years. At Yucca Mountain, PAM was not needed to establish acceptable densities of plants.
- Use of rock or gravel mulch as a treatment in the reclamation trials was suggested; however, due to the lack of rock and the presence of deep soils on the heavily disturbed sites, it was suggested that gravel mulch would not stay on the surface after disturbance events. It was noted that this treatment could be tested in a separate trial.
- Some workshop participants proposed that naturally occurring soil features such as biotic crusts, natural rock cover, and pavement areas should be considered as treatments to control erosion.

V. MORRILL COMMENTED THAT WHILE SERDP FUNDS ONLY BASIC AND APPLIED RESEARCH, THERE ARE OTHER POSSIBLE FUNDING PROGRAMS FOR A DEMONSTRATION PHASE OF THIS PROJECT THAT ARE INTENDED TO ADDRESS TECHNOLOGY TRANSFER. SHE IDENTIFIED THE "LEGACY PROGRAM" AS A POSSIBLE SOURCE FOR THIS FUNDING.

A possible contact for identifying soil inoculants is Dr. Elaine Ingham at Soil Microbial Biomass Service located at Oregon State University.

In addition to PAM, Dri-water may also be investigated. A contact for Dri-water is Carl Wood at New Mexico State Univerisity.